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MACHINE DESIGN

June 1943

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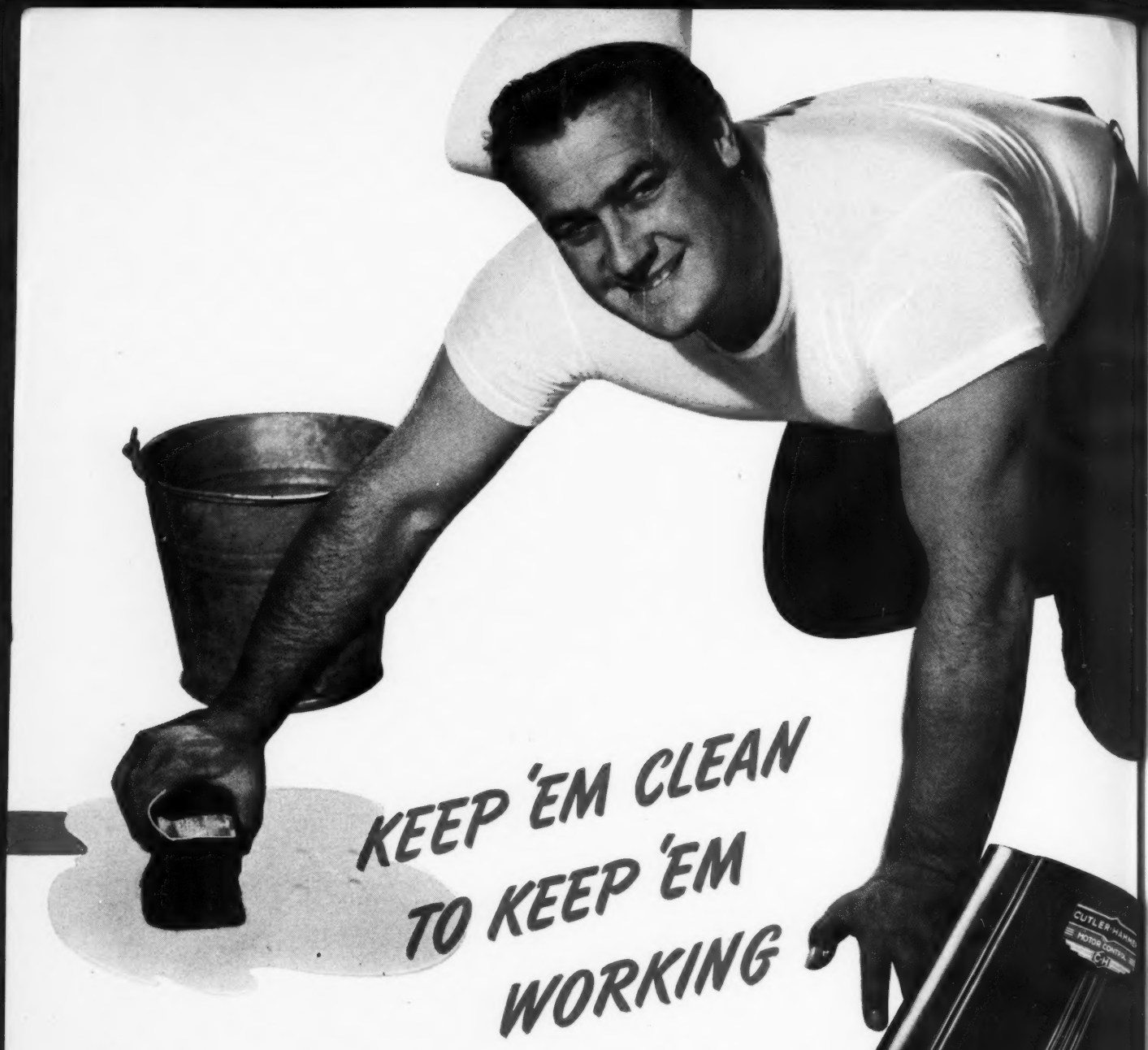
Plywoods in Aircraft



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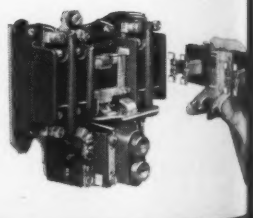

MACHINE DESIGN

THE PROFESSIONAL JOURNAL OF CHIEF ENGINEERS AND DESIGNERS

Volume 15 JUNE, 1943 Number 6

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This simple gyroscope, a toy top, is the father of the automatic pilot in our big bombing planes—the marvelous gadget our boys call "Elmer."

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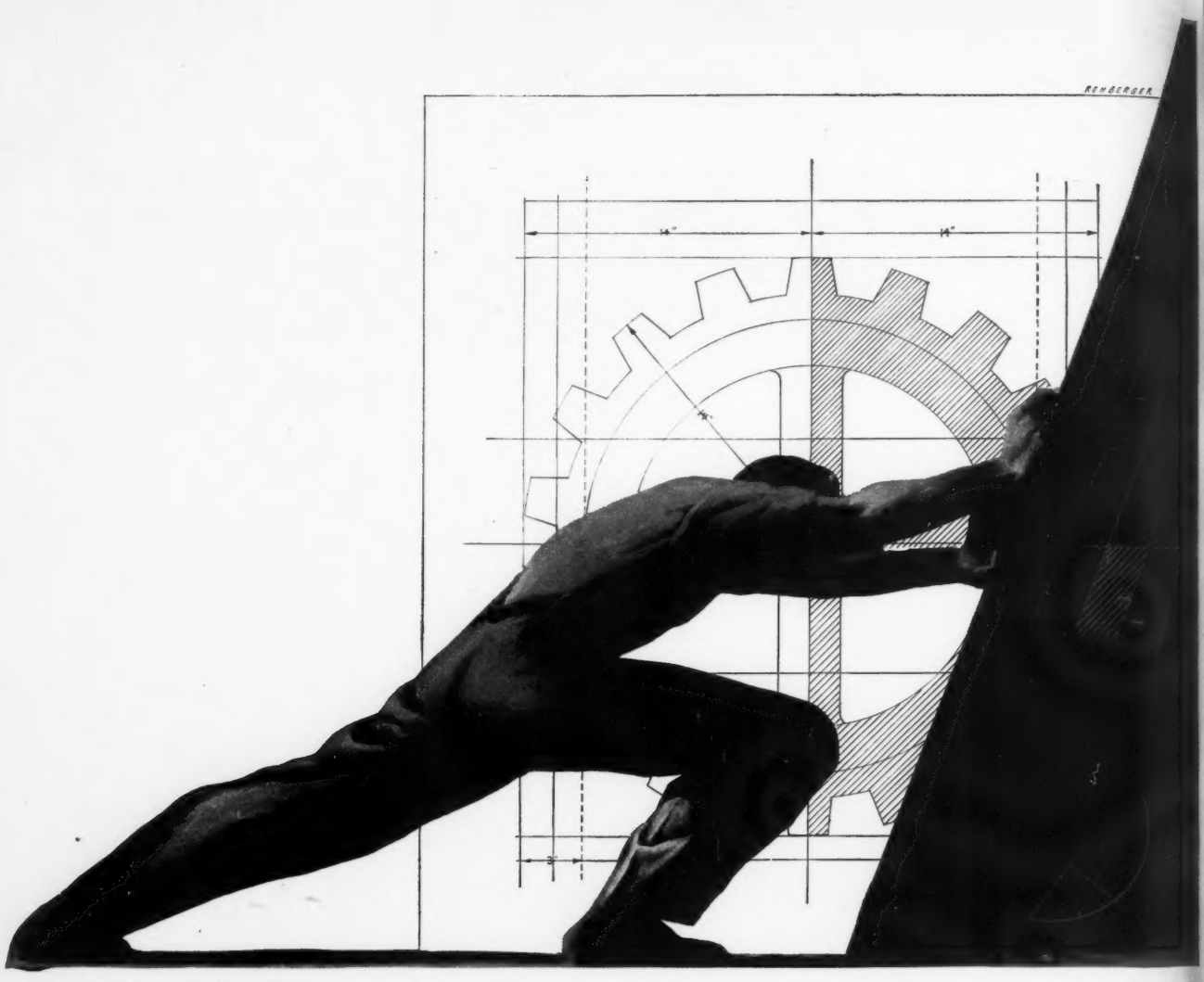

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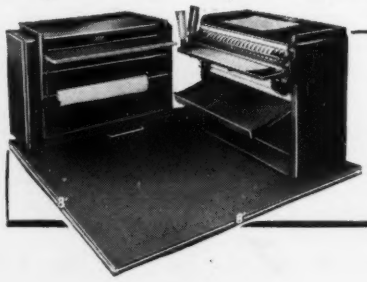

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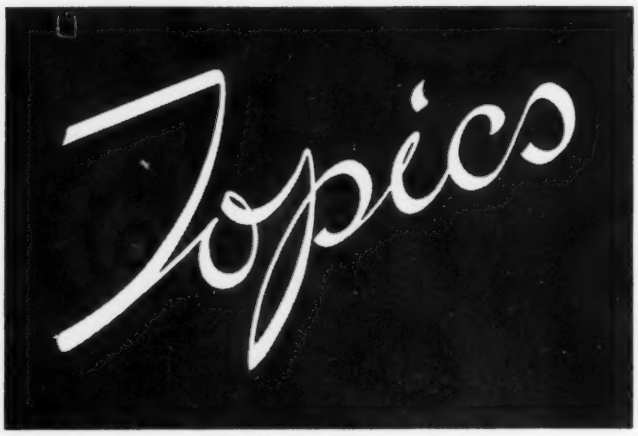


RADAR — code name for radio detecting and ranging — has officially been revealed to be one of the foremost scientific developments of the war, permitting the discovery of targets invisible because of darkness, smoke or clouds, and providing data for guns to direct an exact fire pattern on such targets at the maximum reach of the largest known guns. An electronic instrument, it projects a beam of radio impulses through space at the rate of 186,000 miles a second. In much the same manner as the beam of a powerful searchlight discloses the location of a signboard at night, these impulses reveal the presence of distant objects such as airplanes, submarines, and battleships by rebounding to the observer. A cathode tube acts as an interpreter and makes the electronic signals visible tc the human eye.

AN ELECTRONIC "sewing machine" employing radio frequencies instead of needle and thread joins thermoplastic fabrics in airtight, waterproof seams. By inducing heat in the synthetic cloth the device welds a seam stronger than the material.

QUICK-DRYING COATING, now available, permits easily read dimensions, reference points, etc., which are scribed onto the stock before machining. This industrial finish layout dye, which is semitransparent, extremely fast drying, and purple in color, is brushed on the sheet metal and dries in about a minute. Layout is then scribed with a sharp-pointed stylus or scriber.

ALLOY CAST IRON has replaced brass in one-piece, three-bladed propeller castings being produced for Coast Guard vessels. The material—Meehanite metal—has passed rigid inspection and testing, proving its strength and structural characteristics.

FIRST SYNTHETIC RUBBER TIRE made entirely of government-produced materials has just been completed. The only difference from a conventional tire is the date molded into both sidewalls. Size of the new tire is that suitable for the U. S. Army "jeeps".

MOLDING of thermosetting materials by high-frequency current, utilizing electronic equipment in conjunction with present compression and transfer-molding equipment, shortens curing time from 1/10 to ½ and reduces pressure as much as 30 to 40 per cent. Also molding of impact - resistant phenolic preforms can be accomplished readily. Thicknesses of ⅛-inch thermosetting materials and greater can be molded in cycles as short as that for thermoplastic materials on injection-molding machines. Compression molding of pieces thicker than ⅜-inch is also possible.

PLASTICS conserve aluminum and iron hitherto used for patterns and core boxes in the manufacture of steel castings.

IF IMPROVEMENT in synthetic rubber continues at the rate of the past two years, it will not be unreasonable to expect developments which will bring about production of synthetic tires to last the normal life of a car. This is indicated in a recent test run determining the value of a new black carbon in synthetic rubber tires. Under a 35 per cent overload, the tire traveled 37,000 miles at 60 miles per hour.

SINCE 1901 when General Electric Co. started its apprentice training course, there have been 2524 graduates. Still with the company are 1400 of these, and only 4 per cent are doing work entirely foreign to their original training.

PINT-SIZED automatic transmitters to save the lives of American pilots adrift and in distress at sea have been supplied to many planes. Called "Gibson Girl" affectionately because of the wasp-like waist of the unit fitting between the knees for easy operation, a built-in keying device sends out international S-O-S signals over an area of more than 40,000 square miles. For raising the aerial in any weather, a balloon and kite are packed with each kit.

MARKET SATURATION within three years after peace is seen by the refrigeration industry. New sales appeals will include transparent plastics for food compartments, a combined three-unit refrigerator—food storage and ice cube compartment, a 10-degree Fahr. compartment for frozen foods and a quick freezing unit that would go well below the zero range—as well as utilization of the warm air for a storage compartment for cereals and similar foods.

MACHINE DESIGN

Fig. 1—Resin-bonded plywoods form wings and fuselage of this airplane

Utilizing Molding and Forming for Aircraft Plywood

By John Delmonte
Technical Director
Plastics Industries Technical Institute

NEWER developments in resin-bonded plywoods are particularly noteworthy because they not only make possible many of our aircraft and accessories, but also reflect the ingenuity of engineers in devising efficient methods of applying pressure and generating heat. Advantages of resin-bonded plywoods are well recognized, particularly for their high strength-weight ratios. Synthetic resins such as the phenol-formaldehydes, urea-formaldehydes, melamine-formaldehydes, and polyvinyls have already made possible outdoor, weather resisting grades. Further advantages have accrued through full resin impregnation (about 30 per cent) into the wood veneers, resulting in a more dimensionally stabilized structure. Failure to apply resin impregnation in the correct manner and in the proper application, or neglect of proper moisture control in the wood before as well as after laminating has been responsible for unfortunate experiences in bonding

various plywood parts.

Correct combination of plastic materials and wood veneers, for molded plywood shapes such as boat hulls, wing and fuselage sections on aircraft, *Fig.* 1, and numerous accessories must be utilized. The plastics industry has become accustomed to molding temperatures of 300 degrees to 360 degrees Fahr. and pressures of 1000 to 2000 pounds per square inch. It is apparent that these pressure and temperature extremes would limit the number of potential applications unless means could be found to use lower pressures and temperatures. Recognizing these fundamental problems the plastics materials manufacturers have within recent months developed resin binders which would be satisfactory at lower temperatures and pressures. Consequently "cold" setting ureas and "warm" setting phenolics have been developed for many forms of plywood bonding. Bonding or cementing of plywoods are generally divided into the following two categories:

1. PRIMARY BONDING—Assembly and laminating of wood veneers into flat or curved structures generally with the aid of warm or hot setting resin adhesives
2. SECONDARY BONDING—Assembly of laminated wood elements to other laminated woods or other materials, generally with the aid of cold setting adhesives (attachment of fittings or assembly of reinforcing stringers or ribs to plywood skins broadly constitute secondary bonding operations).

Practically all plywood is prepared by primary bonding methods involving various laminated wood veneers to get a balanced structure from the standpoint of strength factors as well as stabilized dimensions. However, plywood itself may be bonded to other wood or plastic members, this being secondary bonding.

Bag Molding Provides Uniform Pressures

Flat-pressed plywood does not offer much of a problem in laminating. When curved shapes, however, are to be reproduced considerable skill must be exercised in building up to a desired curvature inasmuch as plywood or wood veneers cannot be expected to flow, draw, or stretch as may a thermoplastic sheet. After the wood veneers—usually birch, spruce, Douglas fir, mahogany, or poplar—have been assembled, pressing with pressures up to 250 pounds per square inch may be accomplished in one of the following manners:

1. INTERNALLY APPLIED PRESSURE—Veneers assembled against a female die, *Fig.* 2, receive pressure from an expanding rubber bag. A fairly flexible and collapsible rubber bag fills the inside of a closed space which is defined at least on one side by the mold or die and on the other by a pressure limiting plate.

It is sometimes necessary to heat the mold or die, which often is cast from a nonmetallic material such as portland cement, plaster of paris (hydrastone grade), or a phenolic casting compound. However, the main source of heat is from the pressure fluid. Fabricated wood or cast metal dies would be more durable mechanically though more costly. The outside skin of the plywood makes contact with the die surface and reflects the smoothness of this finish.

From a mechanical point of view the most interesting phase of the bag molding technique (internal as well as external pressure) is the uniform application of pressure from fluid or steam piped into the bag. This assembly is readily adapted to applying pressures over large areas as required in airplane construction. The bag, in expanding outward, forces the previously assembled wood veneers and resin adhesives against the die. When the resin adhesives have been fully cured and hence the plywood firmly set, pressure is relieved and the bag withdrawn from the mold.

Still another technique of applying internally applied pressure to a mold or form appears in *Fig.* 3. A half cylinder restrains the rubber bag, insuring good pressure application against the work.

2. EXTERNALLY APPLIED PRESSURE—Also adapted to the laminating of wood veneers into curved plywood forms are rubber bag methods which require an autoclave for developing pressure. In this process, the rubber bag may either be in the form of a close fitting sleeve or glove drawn around the form or a rubber blanket covering the assembled wood veneers, *Fig.* 4. In either case the assembly receives its heat and pressure from within an autoclave. After the assembly has been placed within the rubber bag vacuum may first be applied. This enables the workman to smooth out wrinkles in the rubber bag or blanket by hand until an even, close fit is attained all around the form insuring uniform pressure. Within the autoclave, air pressure may first be developed to bring the veneers and resin adhesives into intimate contact with one another, then full steam pressure is admitted. Unit

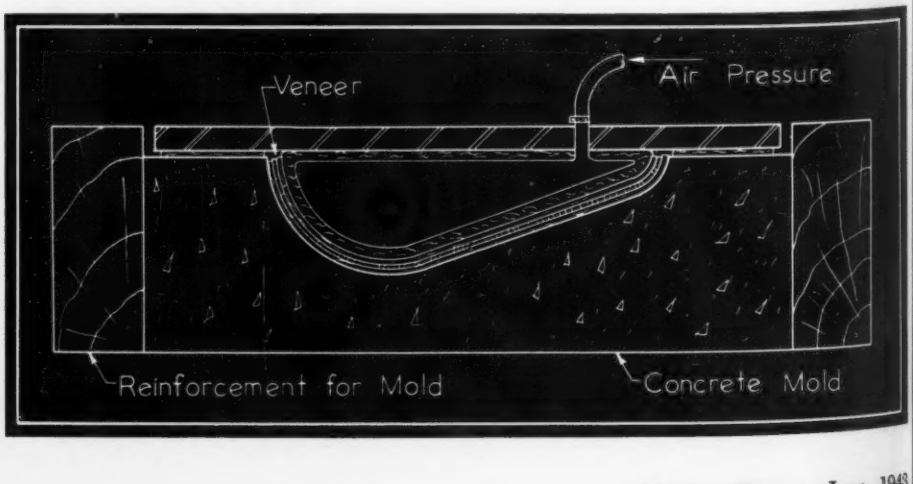


Fig. 2—Internally applied pressure molds plywood against die

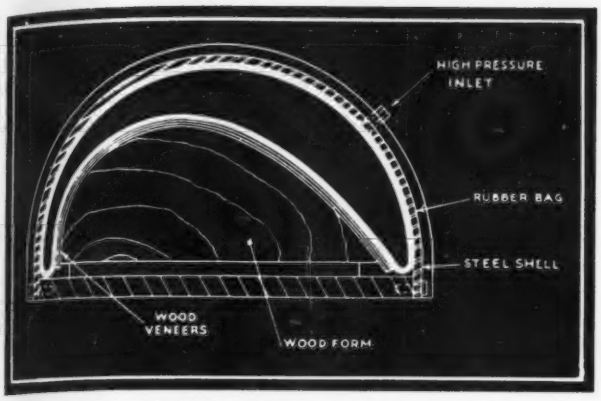


Fig. 3—Above—Half cylinder restrains rubber bag to facilitate internal molding

some ingenuity in the use of castable zinc alloys, which are poured to approximate forms, requiring a minimum of machining.

Forming Is Limited to Simple Curves

Distinguished from the technique of molding plywood, wherein wood veneers are assembled and cured into a final curved shape, is the art of taking flat plywood panels and forming or shaping these to a limited extent. In aircraft work, the synthetic resin-bonded plywoods are employed almost exclusively. Obviously forming is restricted to fairly simple curves or shapes, not allowing double curvatures as may be built up in the rubber bag methods of molding plywood. Where a relatively severe curve is required, steaming the plywood and drying it under clamps in a mold is a common practice. Steaming, however, invites complications through swelling and shrinking, though for some jobs these may be minor factors.

Fig. 4—External pressure forth is molding assembly is applied in autoclave

The largest use of flat aircraft plywood (usually three-ply synthetic resin-bonded veneers) is in the manufacture of the skin on fuselage, wing sections, or tail surfaces. Secondary bonding operations predominate in the application of ribs and stiffeners, using cold setting adhesives in most instances. The application of pressure during the setting of the resin adhesives may involve the use of numerous screw clamps or nailing strips. The latter consist of auxiliary strips of wood which are placed above the sections to be joined such as a rib to the skin or a wing tip, cap strip on wing rib, etc. Nails spaced every few inches are driven in, bringing the plywood into intimate contact with the part to which it is being bonded. After the adhesive has set the nailing strip is removed.

In building large assemblies, plywood panels may have to be scarfed together, and at least a 10:1 degree of scarfing should be practiced for getting the best strength.

In these and in other ways wood veneers and plywood enter the war production program to relieve shortages of sheet metal, producing a functional equivalent to metal. Through the use of synthetic resin adhesives and impregnants, the applications are assured of some permanence which they otherwise would not possess.

SIXTEEN PER CENT of all steels produced in March were alloy steels, about three times the peacetime percentage. Despite the increase, larger demands of expanded production of war machines necessitate strict conservation of the alloying elements.

pressures up to 100 pounds per square inch are common.

The time the assembly is maintained under heat and pressure in the molds depends upon many factors, such as:

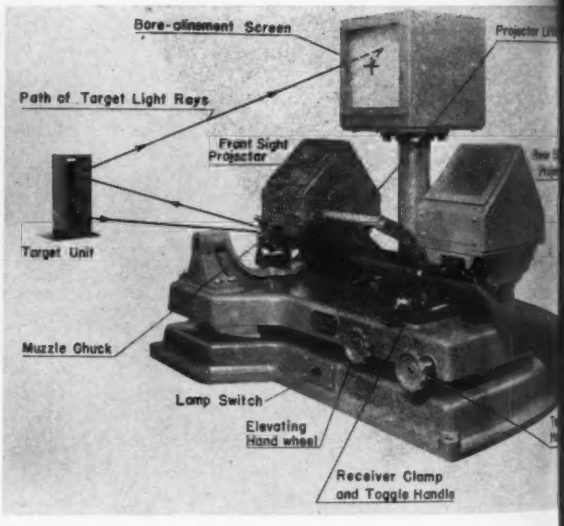
1. Thickness and heat conductivity of rubber bag
2. Nature of resin adhesive and time required for cure
3. Heat conductivity through assembly wood veneers, and overall thickness
4. Moisture content in the wood.

The time may vary from several minutes to an hour or thereabouts under cure. The rubber bag or blanket fulfills another function besides insuring uniform application of pressure. It keeps the wood veneers from contact with the steam or fluid pressure, which may otherwise swell the wood fibers and develop a warped and unsatisfactory assembly.

While the pressures which can be developed are limited in many cases to the available steam pressures or the supertherm hot water pressures, these comparatively low molding pressures permit the use of inexpensive forms or dies of wood or concrete. Unlike conventional plastic molding which is designed for reproducing hundreds of thousands of units from hardened steel molds, resin-bonded plywood productions are numbered in the hundreds. Rubber bags are limited in their useful life, depending upon curing temperature and the amount of stretch in the bag, though reproduction of 50 to 100 assemblies is not uncommon.

In the event that rubber bags prove impractical for a given job, a conventional male and female die may always be employed. The limiting factors, however, lie in the available pressure from hydraulic jacks or screw clamps which would not necessarily insure as uniform a pressure distribution as a rubber bag method. Besides, wood veneers cannot adjust themselves as readily to differences in wall thickness between punch and die as may a moldable plastic. The application of male and female dies in molding plywood assemblies has also reflected

Scanning the field for IDEA



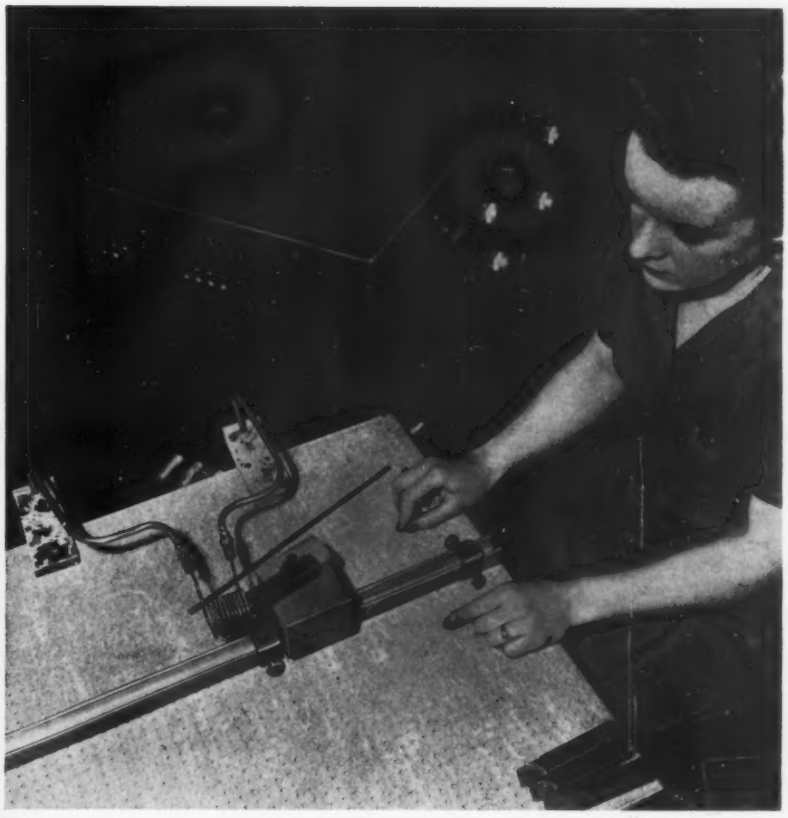
OPTICAL sighting of Garand semiautomatic rifles, above, provides a precision method of shooting light rays at a mirrored target, saving up to thirteen rounds of ammunition as well as allowing a girl to do in a few minutes the job which formerly required two men and a 100-yard rifle range. Because tests show that the last four inches of the bore at the muzzle of the rifle substantially determine the trajectory of the bullet, a bore plug is utilized which contains a concave mirror to reflect the light rays at the target, six feet distant.

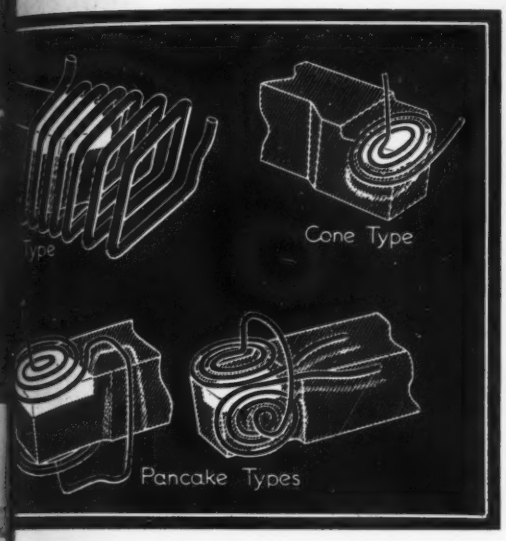
In the instrument, light from the target unit is focussed on the concave mirror on the bore plug, reflected to an adjustable mirror and then back to a mirror on the main fixture which throws the image on a bore-alignment viewing screen as indicated on the diagram. Front and rear sight projectors are optical systems designed to magnify the images of the sights approximately 25 times and focus them on their respective viewing screens. Each projector has a dash pot to prevent it from being jarred when placed in position and individual stops to limit downward motion.

When image is superimposed on cross on bore-alignment screen, the rear gun sight is adjusted so that its image corresponds relatively to that of the front gun sight. These optical adjustments are made to be identical with alignments from a master gun which has been sighted on a range.

Brazing of part assemblies by electronic induction heating has greatly facilitated many manu-

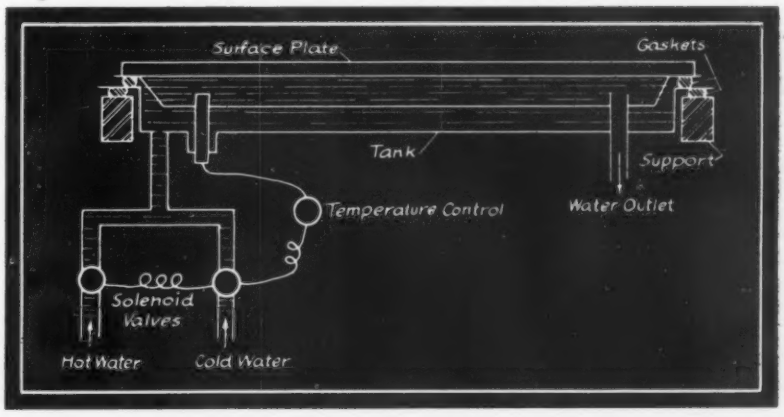
facturing operations and simplified brazing technique. Shown at right is induction equipment employed by the Carboloy Co. for brazing carbide tips on tools. Also, shown below are various types of coils as developed for brazing these tips. Accurate and automatic control is thus provided for production setups, without scale formation nor warping of the brazed parts.

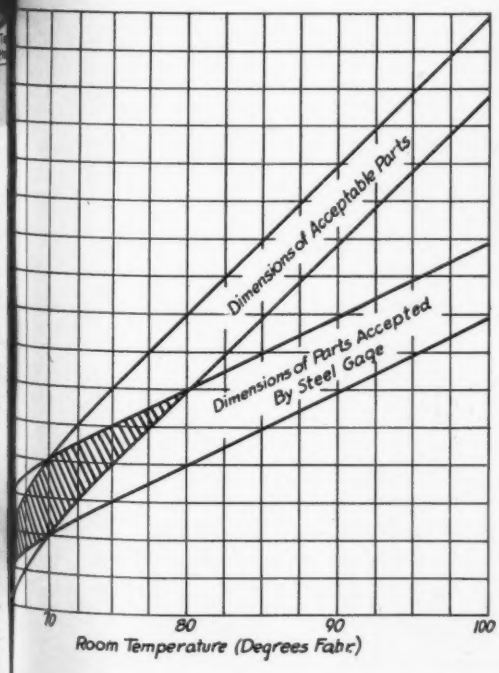




Constant temperature surface plates provide easy solution to reject problems where aluminum parts are checked with steel gages and standards. If there is a ten degree Fahr. differential in temperature, for example, all aluminum parts nominally 6.0000 + .0004 inches would be rejects due to difference in thermal expansion as shown by the chart below.

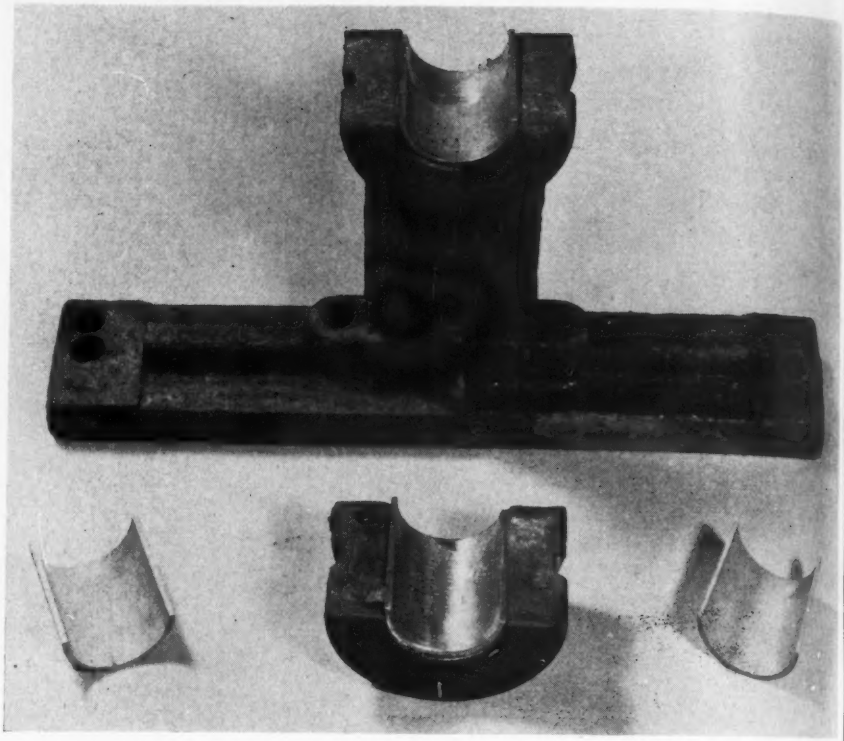
To obviate this difficulty the Union Special Machine Co. designed the surface plate shown schematically below. With this plate, gaging can be done at a constant temperature even when there is a difference of 25 degrees between plate and air to escape. Outside of tank is pointed aluminum and insufficiently large to assume the plate temperature quickly.





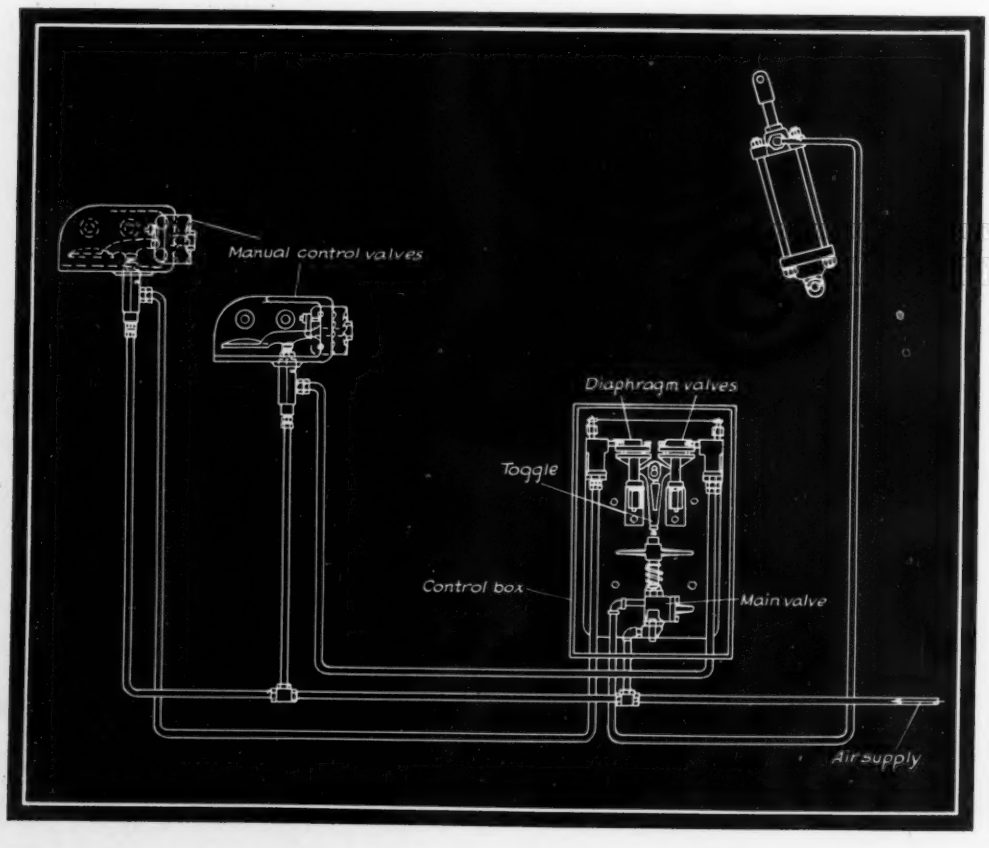
Quarter-inch holes in each rib of the surface plate allow air to escape. Outside of tank is painted aluminum and insulated from its support with a gasket to reduce heat loss. As shown, the water in the tank is under no pressure so the weight of the plate on its gasket will seal enough to prevent leakage. Inlet water is sprayed into tank to prevent formation of hot and cold layers and temperature control is ac-

curate to one or two degrees. To prevent dew condensation on muggy summer days, the temperature is set above the dew point, usually 75 or 80 degrees.



Hard alloy bearings and hard-faced gudgeons operating under adverse conditions and without lubrication in a corn steamer conveyor showed no indications of severe wear after three and one-half years service as shown by the bearing hanger, right. Conveyor shafting is SAE 1020 faced with a Stellite deposited by the oxy-acetylene process, ground to dimensions. Hanger has two inserted half bearings of the same material. Because no lubrication is possible, lest the corn be contaminated, and because some of the paste from the steamed corn gets into the bearings both abrasive and corrosive conditions are present in addition to extreme temperatures. The bearing is a nonferrous alloy containing chromium, cobalt, tungsten together with small amounts of carbon, iron and moly.

Safety control for machines requiring that both hands of the operator be out of danger during operating cycles is simplified by the pneumatic unit shown below. In this control designed by The Prosperity Co. both manual valves must be operated simultaneously in order for the main valve to function. Each manual valve controls a diaphragm valve as shown. When both valves operate together the stem on a toggle unit opens the main valve, admitting air to the clutch trip cylinder, allowing operation for one cycle. If only one manual valve is opened or if both are not opened at the same time, the toggle unit tilts and bypasses the operating stem of the main valve thus precluding any chance for its operation. Release of the manual levers automatically resets the control whether or not the main valve had been opened, effecting a foolproof control.



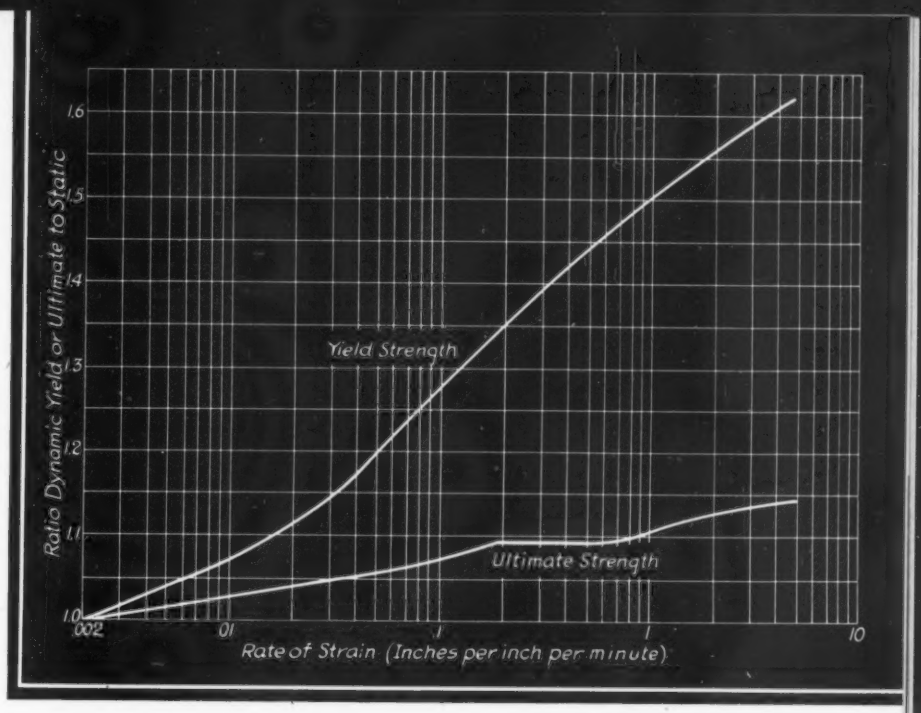


Fig. 1—Right—Shows how dynamic resistance of steel is affected by rate of strain

Fig. 2—Right Below—Impact stress at five points along a struck bar. Horizontal axis represents time

Dynamic Loading in Design

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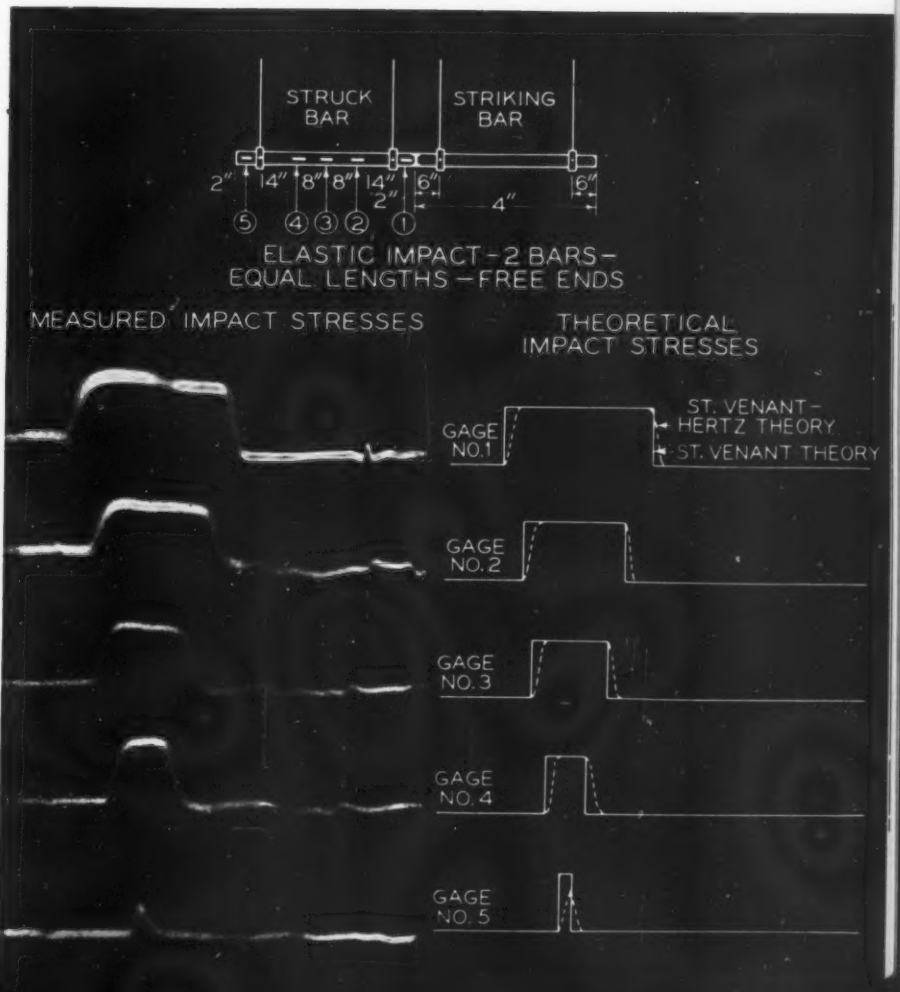
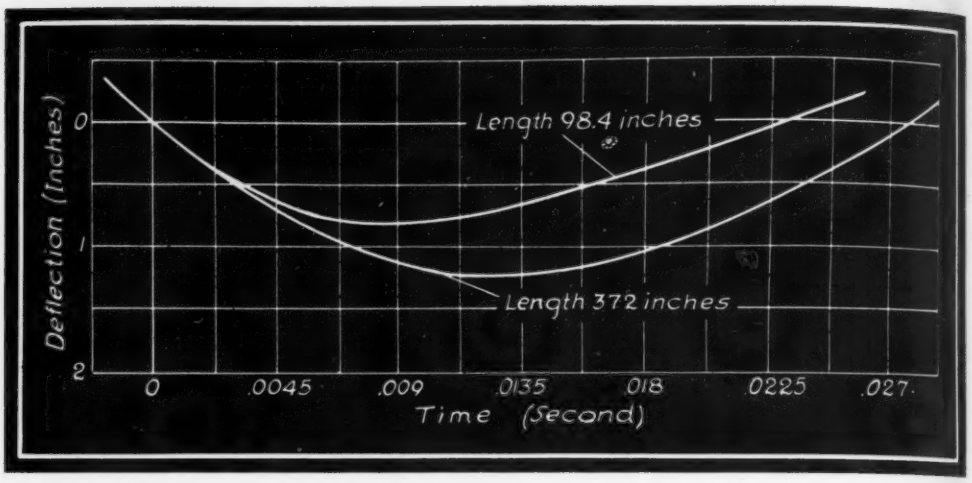


ONE of the primary factors affecting the difference between calculated safe stresses and actual working stresses in machine parts is the fitting of laboratory data on strength of the material to the conditions existing on the job. Major difficulty is to obtain and interpret data on the resistance to fracture under conditions of stress application similar to those that will be encountered in practice. When the design problem is concerned with dynamic loading such as shock, the uncertainties involved reach considerable magnitude. For dynamic problems theoretical calculations are difficult even when the problem is simple, and become impossible in nearly all practical cases. Also, when the load application is dynamic the action of the material in resisting fracture is not fully understood.

Problems of design under rapid dynamic loads or impacts are being studied by many investigators and, although progress seems to be slow, strides are being made both in the cal-

Fig. 3 — Right — Measured deflections of two wires under same impact. Ratio of recovery to elongation time is greater for shorter wire



culation of stresses and in the determination of the dynamic properties of the materials. A review of the complete problem and the results of some of the investigations will be helpful in giving the designer a better understanding and may assist him to interpret and formulate their application to his problems.

Usual method of procedure for cases involving dynamic loading is to increase some static stress value by an amount derived from empirical means. Often this dynamic coefficient is determined entirely by experiment. Methods for doing this include: Measuring the deflection at a part of the structure under dynamic loads and then using the static equivalent; attempting direct measurement of the force applied by imposing a ball to indent a metal plate under the action of the forces and then measuring the static load to cause a like indentation; and measuring displacement, velocity and acceleration on various parts of a structure, then calculating the forces necessary to give the measured acceleration or the energy to give the measured velocity.

Load Rate Affects Behavior

If the method of measurement is based on the premise that the material will behave under dynamic load in the same manner as under static load, the result is not reliable because the material behavior is a function of the load rate. If the method of measurement alters the condition of contact in shock loading (as when the ball indentation method is used), the result is not reliable because the forces generated depend upon the contact conditions. Further, the plastic flow under static conditions may be quite different from plastic flow under dynamic conditions.

Accelerometer measurements are a good method when the load rate is not too high so that frequency is low, but this is usually not the case in shock loading. Velocity and dis-

Fig. 4—Below—Dynamic strain measurement at a point on a punch press during a stamping operation

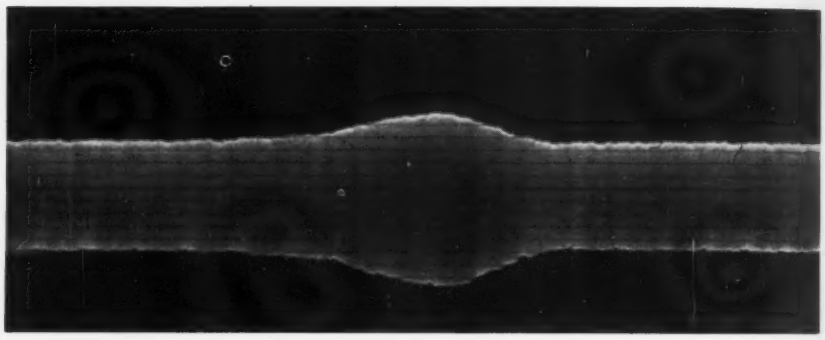
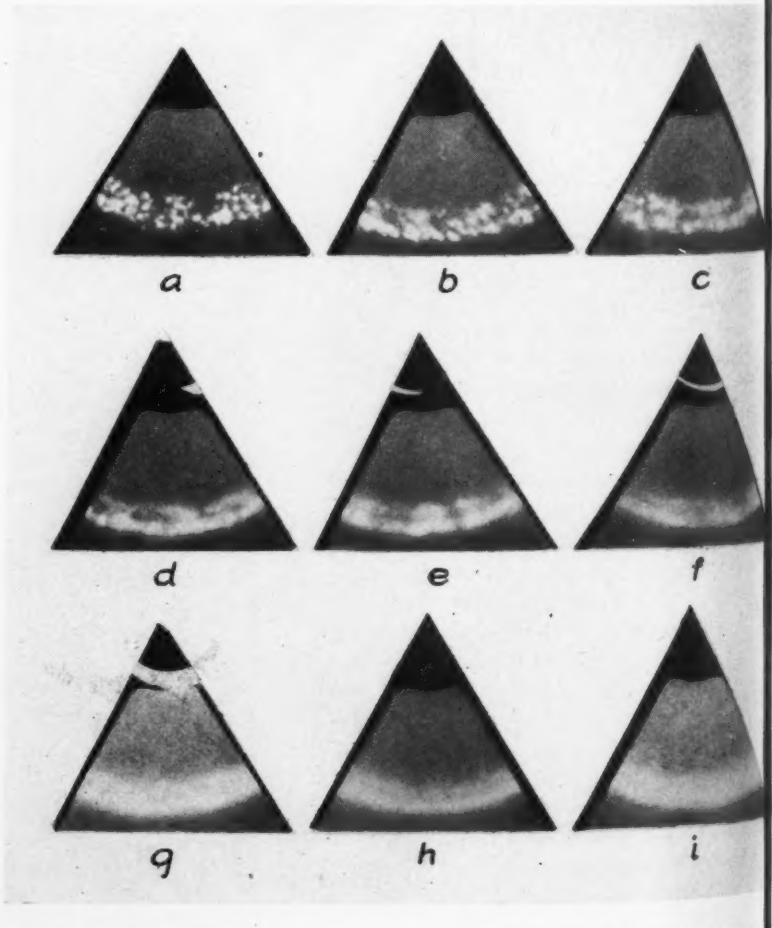


Fig. 5—Below—Progressive change in back-reflection X-ray diffraction pattern with increase in plastic deformation



placement measurements are unsatisfactory because it is difficult to make an accurate determination of the acceleration from velocity and displacement records unless the mathematical function of the record is known or can be approximated by energy considerations.

Notched bar impact tests, such as the Charpy and Izod, show whether a material is tough or brittle in the particular size and shape of the test bar and at the conditions of the test as to temperature and impact velocity but give little real information concerning basic impact phenomena and the ability of the material to resist impact forces. To select material to resist dynamic loads on the basis of a notched bar test gives a false sense of security concerning the use of the material. More fundamental information concerning the basic action of the material in resisting fracture under impact is essential before data on the notched bar methods of testing can be used to their fullest value.

Newer specifications on many articles require a shock test of the completed structure. Evaluation of the shock in order to compare field conditions with laboratory is difficult to make on a rational basis. A shock or impulse

TABLE I

Comparison of Dynamic and Static Yield

Material	Ratio	Investigator	Date	Reference‡
Steel Wire	1.68	Hopkinson	1905	2
Copper Wire	1.28			
Steel	1.85	Dinnik	1909	4
Steel	1.90	Nemiloff	1910	5
Steel	1.33	Plank	1912	6
Steel	1.23-1.44	Davidenkoff	1913	7
Iron	1.60	Meyer	1927	12
Steel	1.10-1.43 Relative, not absolute	Davidenkoff & Jurieff	1930	14
Steel	1 00	Guest	1930	15
Steel Strip	1.52-1.60	Winlock & Lieter	1937	19

‡References are listed at end of article.

is usually denoted by $F\Delta t$ where F is the force and Δt the time the force lasted, and for a structure this quantity may have a complicated form. For a given device the impulse is often taken as $a\Delta t$ where a is the acceleration of the impacting mass. The problem is further complicated by the possibility that the resistance to shock of a given material or structure is not fully understood. It is difficult to determine if a shock of 2,000g acceleration lasting for 1/1000 of a second is more or less disastrous than a shock of 200g acceleration lasting for 1/100 of a second. Acceleration-time curves taken in the field in a great many cases are complex, and to perform laboratory tests at simliar shocks and like conditions is extremely difficult.

If a part is acted upon by a set of forces applied at an extremely rapid rate it does not at once take up the type of motion and state of stress predicted by elementary mechanics. The part does not behave as a rigid body and the stress and motion radiate throughout the part in the form of waves originating at the points of application of the forces. In the case of elastic metals these waves travel at high speed and store elastic energy as well as change the state of motion of the body as a whole. When the body is not perfectly elastic some of the energy is stored elastically, some is stored by change of motion, and some is dissipated by the friction of plastic deformation. Although in the case of slowly applied forces, a compatible homogeneous state of stress and uniform motion exists in each element of the body at the same instant, this is not the case when forces are applied at a faster rate than they can be transmitted throughout the body.

Transient Stress Distribution Is Complex

When the waves generated by a rapidly applied force strike its boundaries they may be either reflected or transmitted to the surrounding medium. In general a complicated action is set up where some of the wave is reflected and reverberated within the domain of the material composing the body, and some is wholly or partially transmitted from the body. If the material is highly elastic and the forces acting are not too large the net result after a short time is to bring the state of stress and motion of the body up to values very close to those predicted by elementary elastic theory. Time necessary to bring about this effect is controlled by the size and elastic characteristics of the body. If the material is partially elastic (such as steel) and the forces acting are large, the problem is more complex and the loss in energy caused by plastic flow or internal friction is extremely difficult to trace. In elementary mechanics this is explained away by the use of a coefficient of restitution. However, the coefficient of restitution cannot depend only on the nature of the materials involved in an impact but must also depend to a large extent upon the shape of the bodies.

Due to the difficulties of measuring rapidly varying quantities such as strains due to impacts, little definite knowledge about the manner in which material is able to resist the action of dynamic loads has been uncovered. Results of investigations agree on only a few basic points. The wide variation is probably due to the different materials used, different techniques established, and different interpretations placed on laboratory readings. The only established fact is that the resistance of the material is affected by the rate of application of the force. However, no real agreement has been reached on the basic question of change, as a function of force rate, in the region of elastic effect as compared to the region of plastic effect. TABLE I shows the results for a group of investigations comparing the ratio of dynamic to static yield.

Dynamic Yield Affected by Deformation

Except for the results of Guest, these investigations are at least in agreement on the fact that a raise in yield is experienced. The difference is due to the fact that all investigators except Guest depended upon relatively large permanent deformation to determine passage of the yield point, while Guest—using coefficient of restitution and highly accurate measurements—could determine his result with a greater degree of precision. It is possible to conclude that some grains of the material will take permanent set or undergo plastic deformation independent of the speed of the load application. If the determination of yield depends upon obtaining a predetermined set, then when the time to give a measurable permanent set is longer than the time of application of the force, an increase in yield strength will be recorded. This explanation reveals that the methods employed did not have the

necessary accuracy to sort the plastic action from the elastic action at high rates of load application. It may be that for design purposes a permanent set of measurable amount is important to determine whether or not a dangerous condition exists, but for any adequate impact theory it is necessary to determine when plastic deformation comes into play, what amount of plastic effect is obtained and how it is distributed. If the results of Guest are correct, it is possible that for a body of concentrated mass to collide with another body not of concentrated mass without having the collision cause plastic flow, the ratio of relative velocity of approach to the velocity of sound in the material itself must not exceed the static yield strain. Also, the energy contained in the striking body must not be greater than that required to cause a stress storage in the struck body above the elastic strength of the body.

High Rate of Strain Raises Tensile Strength

The results of Winlock and Leiter in TABLE I were obtained for a wide variety of strain speeds, and a plot of the relation for various speeds is shown in *Fig.* 1, which also includes the ratio of dynamic ultimate load to static ultimate load. Results of other investigators for this ratio are given in TABLE II.

Values of the investigations listed in this table point to one general conclusion, that the tensile strength of the material is higher under dynamic conditions than static conditions. The higher ultimate and yield stresses under dynamic conditions agree with the statement by Love†: "It appears that very great stress acting for a very short time, of order of magnitude of one thousandth of a second or less, does not necessarily cause any dangerous set, or fracture, when the stress exceeds that of the static yield point. Such stresses may without sensible error be calculated by mathematical theory of elasticity, as if there were no such thing as limits of elasticity."

Shock Wave Has Speed of Sound

In making any analysis of shock it is necessary to consider the rate at which a shock wave can distribute itself throughout a given material. It is found to be $v = \sqrt{(E/\rho)}$, where E = Young's Modulus and ρ = mass density. This is the same as the expression for the velocity of sound in the material. For steel the value is 16,800 feet per second. *Fig.* 2 shows strain-time measurements for five points on a free-end bar struck with a second bar of like geometry. Theoretical values also are shown in *Fig.* 2 and a direct comparison can be made. The length of time that the strain exists is a function of the velocity of propagation of the strain wave. Accurate measurements of these lengths to determine the velocity of the wave travel show little if any change in the modulus of elasticity with the rate of strain application, from which it can be concluded that the elastic modulus as measured statically is essentially correct for dynamic loads.

When a weight strikes the end of a long wire, simple analysis assumes a state of homogeneous stress to exist at any time t after the blow has been delivered. This assumption gives reasonable agreement with actual experience so long as the energy of the striking mass is not large enough to cause plastic deformation.

An expression for maximum stress can be derived by applying the principle of conservation of energy. Equating the kinetic energy of the striking mass at the instant of contact to the elastic energy stored in the wire at maximum deformation:

$$\tfrac{1}{2} M V_o^2 = \tfrac{1}{2} \frac{S_{max}^2}{E} A L$$

or

$$S_{max} = V_o \sqrt{\frac{E M}{A L}}$$

The assumption of homogeneous stress cannot be used when the striking mass is not many times more rigid than the struck body, and the problem becomes extremely complex. Method of attack when more rigorous theory is necessary is beyond the scope of this article, but is fully discussed in References (3) and (15).

When the energy of the striking mass is much greater than that which can be stored in the struck body at stress values below the static yield strength, the problem is many more times complicated. *Fig.* 3 shows deflection-time curves from a blow on a long wire specimen. The energy of the striking mass was many times that of the ability of the specimen to absorb it at stress values below the static yield. In these measurements the deflection of the specimen was measured at the end by the use of a small mirror that threw a beam of light on a rotating film. Although a rational analysis of these curves is not possible, some information concerning the behavior of material under these conditions of impact can be gathered. The deflection-time curve during the elongation period appears to follow an elastic or conservative type of deflection. The form of this curve for that period appears to be $\Delta = \Delta_o \sin \mu t$, where Δ_o is the maximum deflection and μ is a constant. This type of curve not only gives points that fall on the experimental curves but satisfies the conservation of energy relation. The curve during the release period does not follow this type of function and indicates that energy is dissipated when the load is released. The material appears to resist the shock through the medium of elastic forces plus a set of extra forces also proportional to the displacement on application but not acting on the release. If elastic constants are assumed on the basis of static measurements, the calculated maximum stress is higher than the measured value and the time of elongation is shorter.

In order to discover what actually happens an experiment of this type is far from adequate, and measurements

TABLE II

Ratios of Dynamic to Static Ultimate Strength

Material	Ratio	Investigator	Date	Reference†
Steel	1.46	Plank	1912	6
Iron	1.12	Seehase	1915	8
Steel	1.06			
Brass	1.01			
Copper	1.13			
Steel	1.14	Meyer	1927	12
Copper	1.15			
Brass	1.02			
Iron	1.11			
Steel	1.08-1.13	Winlock & Leiter	1937	19

†References are listed at end of article

† "Mathematical Theory of Elasticity", Page 117.

of plastic flow and permanent strain distribution, as separate from the elastic strain distribution, must be determined. To do this two types of equipment are available in the laboratory, the electric strain gage for measurement of the overall strain at a point, and the X-ray diffraction to measure the extent of the plastic strain at that same point. A short discussion of these two laboratory tools in their present state will show what promise exists for determining the action of material in resisting dynamic stresses.

The electric strain gage of the wire-resistance type is useful for making overall dynamic strain measurements, as it has no moving parts and is simple to apply. Basic element of this gage is a grid of fine alloy wire cemented to a layer of paper which in turn is cemented to the material to be stressed. Any change in strain in the member will change the length and cross section of the wire and its resistance will vary. Choice of the wire for the gage depends upon the relative importance of temperature variation and sensitivity. In static measurements care is needed to keep the temperature effect to a minimum. In dynamic work the effect of temperature changes is not serious as the strain measurement is made in such a short interval of time. Gages based on this principle have been made to work with extremely small gage lengths. Limitations on the use of this type of gage come not through the gage unit itself but rather in the limitations of the electric circuits necessary to detect the small resistance changes caused by the strain.

For dynamic strain measurement the best circuit depends upon the rate of variation of the strain to be measured. When the rate is slow and of fairly long duration the amplitude modulation type of circuit works well. The idea is to place the strain gage resistance as one arm of a balanced alternating-current bridge, then any change in strain in the member to which the gage is attached will cause an unbalanced voltage across the bridge. To determine direction of strain, that is, tension or compression, the bridge is thrown slightly out of balance electrically. A strain of one sign will then tend to place the bridge in balance and the strain of opposite sign will tend further to unbalance the bridge. The voltage across the bridge is usually at high frequency, about 2000 cycles. This voltage can be amplified by an amplifier designed to have its peak response at the frequency of the power supplied to the bridge. The amplified signal can be applied to a cathode ray oscilloscope which allows high frequency carrier to be used. *Fig.* 4 shows the modulated strain record made on a punch press during a stamping operation. The band width at the left denotes zero strain and the widening of the band denotes a tension strain. Frequency of the load for this type of recording should be not more than 10 per cent of the carrier frequency.

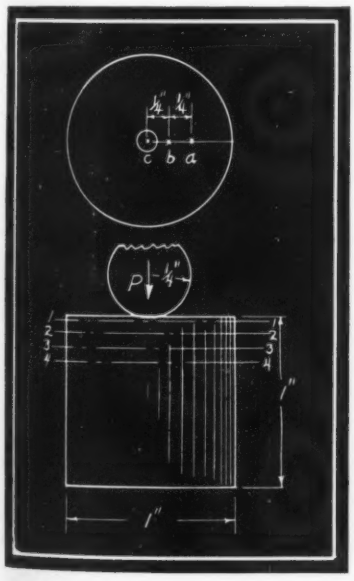


Fig. 6 — Left — This piece was statically loaded as shown, then a similar piece subjected to equal dynamic load. X-ray diffraction patterns at several points were then compared

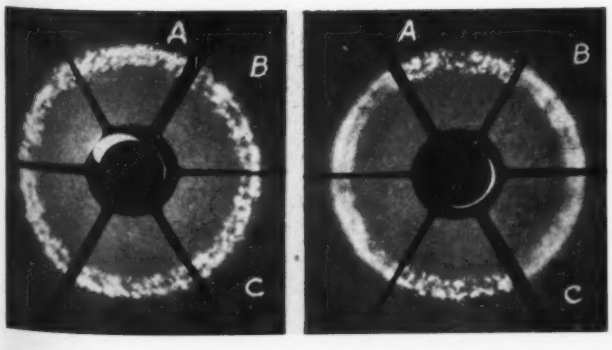


Fig. 7 — Below — Compares X-ray diffraction patterns on plane 4 (Fig. 6) for static (left) and dynamic (right) loading

Responds to Extremely High Frequencies

When the dynamic load is applied at an extremely rapid rate the potentiometer circuit is best suited for the purpose. In this hook-up the strain gage is arranged in series with a fixed resistor and a battery. Potential drop across the strain gage varies with the strain in the material. This circuit is capable of response to extremely high frequencies but has the serious limitation that it requires dynamic methods of calibration. Units of this type give a trace of strain against time directly on the oscilloscope. The oscilloscope records of the strain in the pendulum bars, *Fig.* 2, were determined with this type of equipment. It can be seen that flat response at high frequencies is obtained.

Effects of plastic flow, and permanent set such as crystal lattice distortion and crystal break-down can be determined by the use of X-ray diffraction patterns. These patterns give some indication of the extent to which a given piece of material has been subjected to plastic flow. The back reflection technique of obtaining diffraction patterns allows a small beam of X-rays—about .01-inch in diameter—to impinge on the surface of the metal to be examined. This small ray is reflected back to a film.

Plastic Deformation Changes X-Ray Pattern

If a metal has not been under a strain large enough to cause permanent set a picture like that shown in *Fig.* 5*a* is obtained. If the material has experienced a strain just large enough to cause plastic deformation and permanent set the picture is like *Fig.* 5*b*. As the deformation due to plastic flow is increased the pattern changes as shown in *Fig.* 5*a* to *Fig.* 5*i*. A set of pictures for a given specimen gives a yard stick with which the extent of permanent deformation may be approximated.

A simple experiment shows how this technique is useful in determining the difference between plastic flow due to static loading and that due to dynamic loading. Two

specimens of the dimensions shown in *Fig.* 6 were prepared. A steel ball one-half inch in diameter was placed in the center on the top and struck a sharp blow with a hammer. A dent .012-inch deep was formed in the top of the specimen. The second specimen was then placed in a press until a dent was formed by the ball also .012-inch deep the same as under the dynamic condition of loading. X-ray diffraction patterns were then prepared for positions *a*, *b* and *c* for each of the four planes shown in *Fig.* 6. Typical results of this experiment are shown in *Fig.* 7 which are prints of the X-ray diffraction patterns for plane 4. A difference of plastic flow is evident and a graphic representation of the results is shown in graph form in *Fig.* 8. The results are approximations of the extent of the permanent set obtained. This method of analysis can be developed to a greater extent and will give definite information on plastic deformation even when rates of change are extremely high.

Although it is still necessary for the designer to base his selection of working stresses on experience from similar problems, hoping that his predictions are not too far removed from actual conditions, the new methods discussed in this article offer greatly improved techniques.

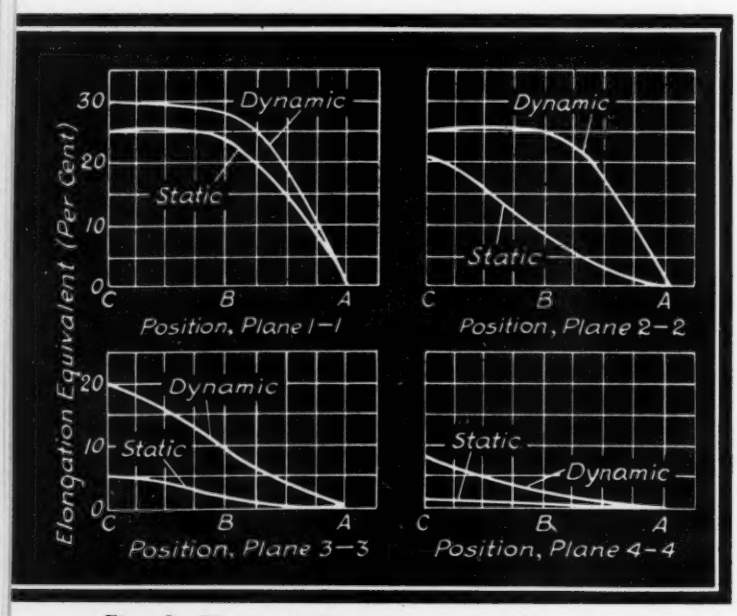


Fig. 8—Plastic deformations in vicinity of ball-point loading (Fig. 6) compared for static and dynamic loading

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"As a Duck Takes to Water"

NOW in action with U. S. fighting forces in war zones, the Army's new quarter-ton, four-wheel drive amphibian car has a carrying capacity of five men and can ford a river, navigate a lake or even operate in seas that a boat of comparable dimensions can weather. A power-driven capstan or winch in the prow of the boat enables it to pull itself up the bank of a river by hitching a rope to a tree or other object on shore.

Structure is designed so that normal type chassis frame could be used, insuring proper weight distribution for land operation and permitting installation of the motor, transmission, radiator core, fuel tank and other parts within the frame before assembly within the hull. Many

parts are interchangeable with quarter-ton truck parts, facilitating manufacture, service and repair.

Sea-going accessories include a device for sealing the engine against water penetration when waves break over the bow and a bilge pump. Development of a satisfactory self-priming pump necessitated considerable redesign to obtain light weight with maximum capacity.

Designed and built by the Ford Motor Co., the new transportation unit employs controls which are identical with those of a quarter-ton four-wheel drive reconnaissance car, no steering changeover being required from land to water operation.

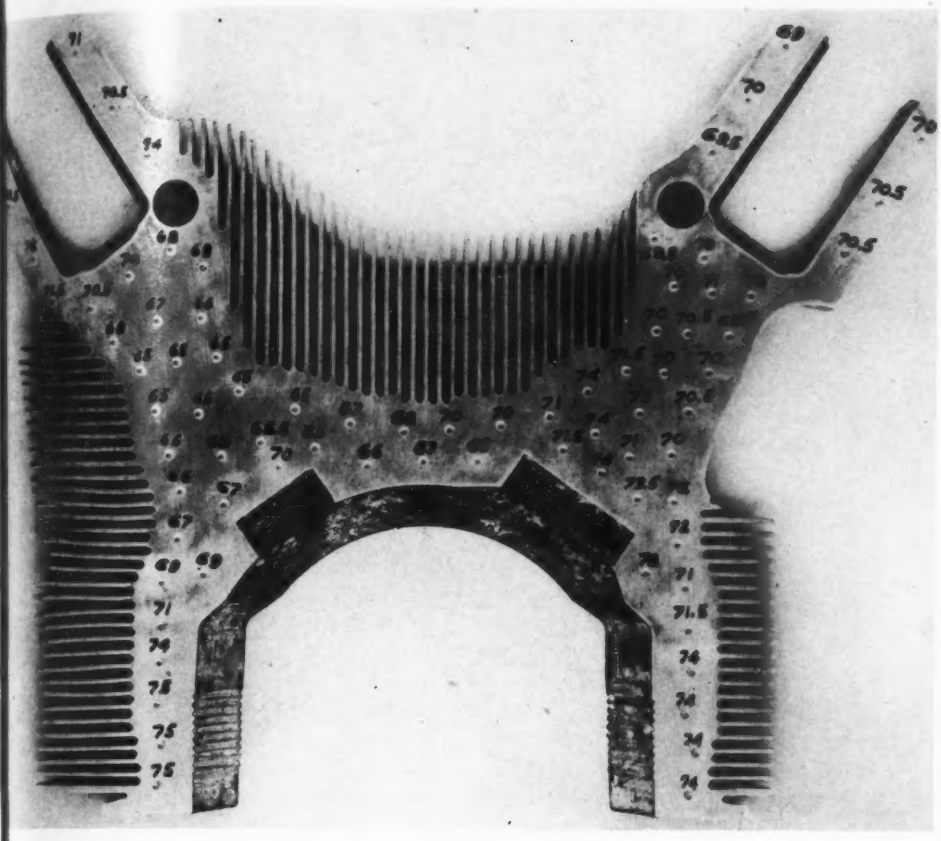

Fig. 1 — Section through forged aluminum cylinder head for air-cooled engine. Brinell numbers indicate reduced hardness due to operating temperatures

Detecting Working Temperatures by Hardness Drop*

By E. J. Willis
and
R. G. Anderson
Aluminum Company of America
Cleveland

AIRCRAFT engines of today require the maximum output with the minimum possible weight. Using present models as a basis for experimental work, improvements can be made by studying the temperatures and stresses under which the parts operate.

The value of an aluminum cylinder head is determined by its ability to

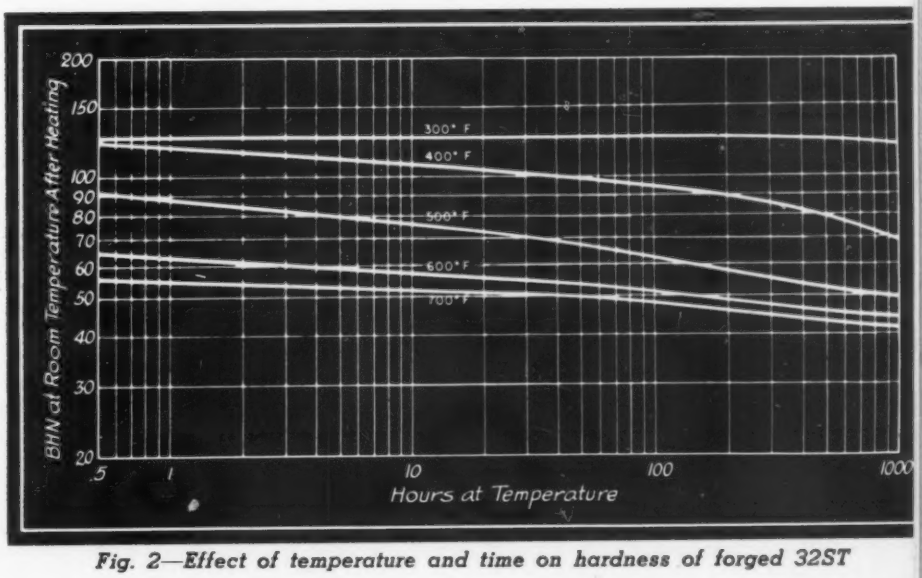

Fig. 2—Effect of temperature and time on hardness of forged 32ST

*Abstract of a paper presented at the recent national aeronautic meeting of the S.A.E. in New York.

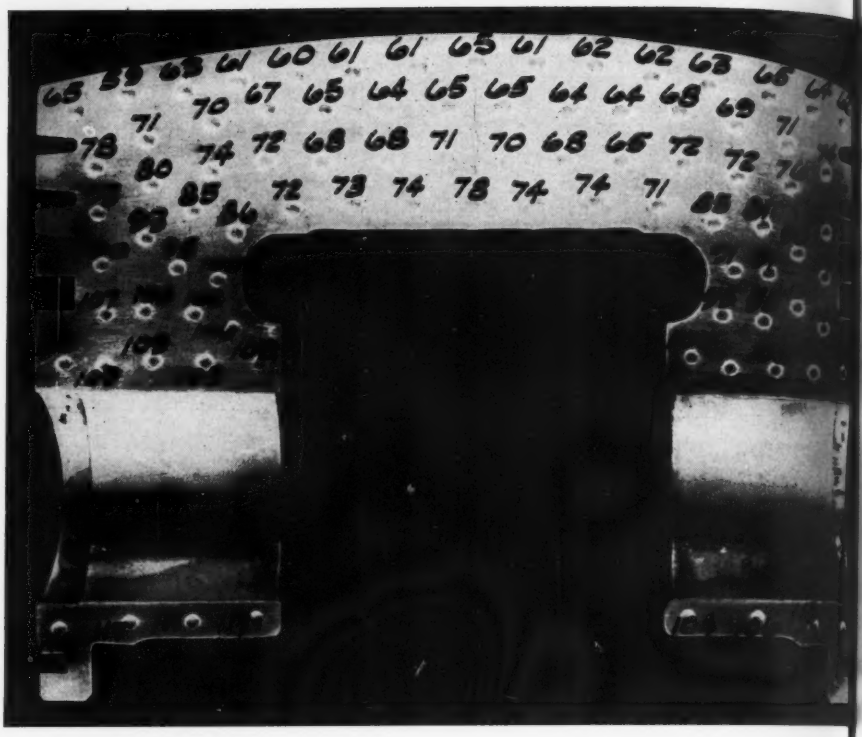

Fig. 3—Brinell hardness numbers at points on section through piston indicate temperatures which were attained during operation

cool and to carry the stresses imposed upon it. At present the proportions of cylinder head fins are not fixed. Usually they are dependent upon the ability of the foundry to cast maximum fin lengths with a minimum spacing between each fin. It has been a policy to put as much fin area on the head as it is possible to cast, but this does not make the best possible use of the material. Due to the advent of the forged head more leniency in both thickness and spacing of fins is available. Since areas around the exhaust ports operate at higher temperatures, the maximum fin areas should be at this location. *Fig.* 1 shows a modern forged head.

To establish operating temperatures of cylinder heads, a method has been worked out which gives the running temperatures of the head. The brinell hardness of the head decreases with the number of hours in service and the temperature at which it operates. If the laws governing the softening of the material are known, it is possible to determine the temperature of any particular spot by brinelling this location after running. The length of time of operation must be known and a particular alloy and heat treatment must be used. *Fig.* 2 shows the relation of brinell hardness with temperature and time for a typical aluminum alloy. The section of the head in *Fig.* 1 has been brinelled to show the variation in hardness. Since the entire head operated a given length of time, all variations in the hardness are indicative of the temperature which the various locations reached.

The stresses under which a head operates include prestresses and fatigue stresses. When the head is assembled with its required inserts, each of these imposes a tensile prestress in the aluminum. For example, the barrel is a shrink fit in the cylinder head. Spark plug inserts, valve seat inserts, valve guide boss inserts, and the various studs also impose prestresses. On top of these are the cyclic stresses imposed by the explosion loads. In addition there are high stresses produced by the rocker arm push rod actions.

Factors Affecting Stress Concentrations

If there were no stress concentrations because of mating parts and sharp radii, it would be relatively simple to determine the stresses at a particular spot in the cylinder head. However, due to the complicated structure this is impractical. The cylinder barrel threads produce stress concentrations both in the radii of the threads and at the top of the barrel. These concentrations can be minimized by proper fits and designs but they are always present. Cylinder barrel threads should match in contour and pitch

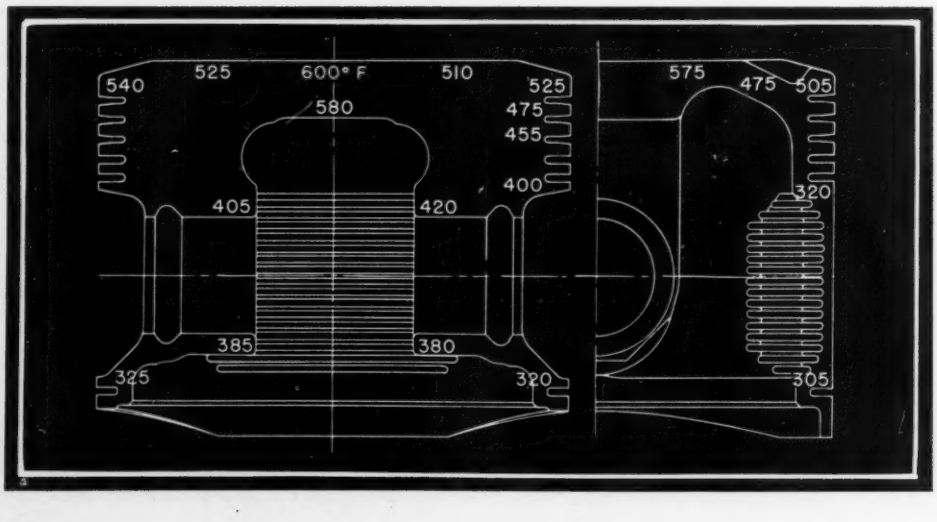

Fig. 4—Figures on section through radial engine piston are working temperatures at various points

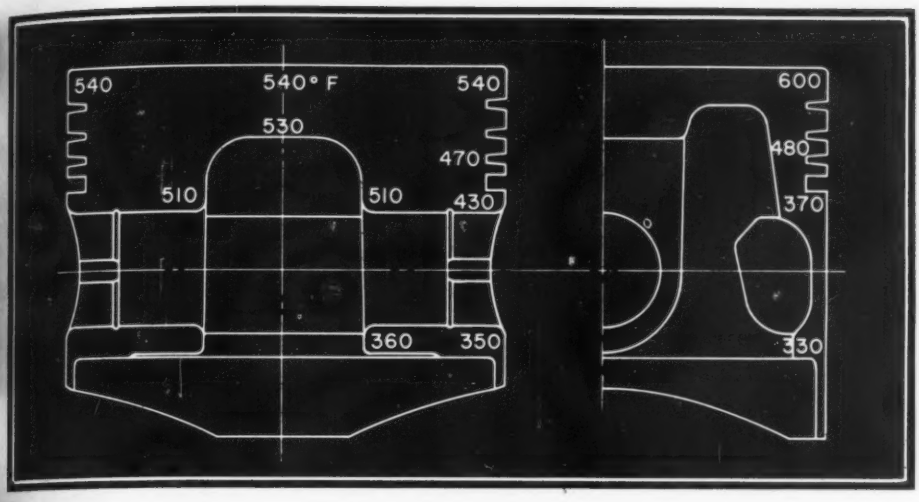

Fig. 5 — Section through piston for liquid-cooled engine is labelled to show operating temperatures

at the operating temperature of the joint rather than at shrink temperature or room temperature. Proportion of aluminum head thickness to steel barrel thickness in the vicinity of the joint and pilot area should be 4.2 to 1 as a minimum design ratio. This takes into account both the difference in modulus between the two parts and the temperatures at which the assembly operates.

The connection between the cylinder head and exhaust pipe has caused trouble from time to time. Shrink fits have been tried with success for the lower output class of engines. When higher horsepowers are required, it is best to use a flange and studs in the aluminum, keeping the exhaust pipe as flexible as possible. Because cylinder head assemblies flex considerably in relation to each other during actual operation, a flexible joint is a necessity.

Liquid-cooled cylinder heads are usually constructed with an inner dome which carries the explosion loads and the various inserts while an exterior jacket retains the cooling liquid. It has been found that this cylinder head jacket must be extremely ductile to withstand the strains imposed upon it. Sometimes the first explosion which the head undergoes strains the material past its yield point at points of stress concentration, causing distortion of the cylinder head under load.

Piston Temperatures Determined

Pistons operate under even more severe conditions than the aluminum cylinder head. Three items greatly affect the operation of the piston. These are temperatures, stresses at various points in the piston, and bending or distortion of the piston and its mating parts. Temperatures involved in this particular part are obtained by the same process as for the cylinder head, namely, the brinell hardness drop method. Many pistons have been sectioned and brinell hardness readings obtained.

One piston which has operated for 250 hours at 200 pounds per square inch brake mean effective pressure is shown in *Fig.* 3. *Fig.* 4 indicates the temperature of a piston for a radial engine during operation. For a liquid-cooled engine typical piston temperatures are shown in *Fig.* 5.

With the temperatures at which these pistons operate fairly well determined it is logical next to survey the stresses under which they operate. It has been found that the strains can be determined quite readily with extensometers, brittle lacquers, and wire strain gages. Of these three, the most satisfactory seems to be the brittle lacquer method. Its ability to operate in constricted areas around ribs and interiors of the piston, which can be only partially covered by mechanical extensometers, is a great asset.

Mating Parts Affect Piston Stresses

Stresses in the head rib are tensile as are those progressing radially from the wristpin hole. The rest of the stresses are compression. This work has shown that the strength of the wristpin and connecting rod have considerable effect on the stresses in the piston. For example, by placing a solid wristpin in a given piston, the tensile stresses around the wristpin hole can be reduced as much as 40 per cent. Of course, this is not practical from a weight standpoint but an approach to this ideal condition can be realized by inserting a plug in the pin to act as

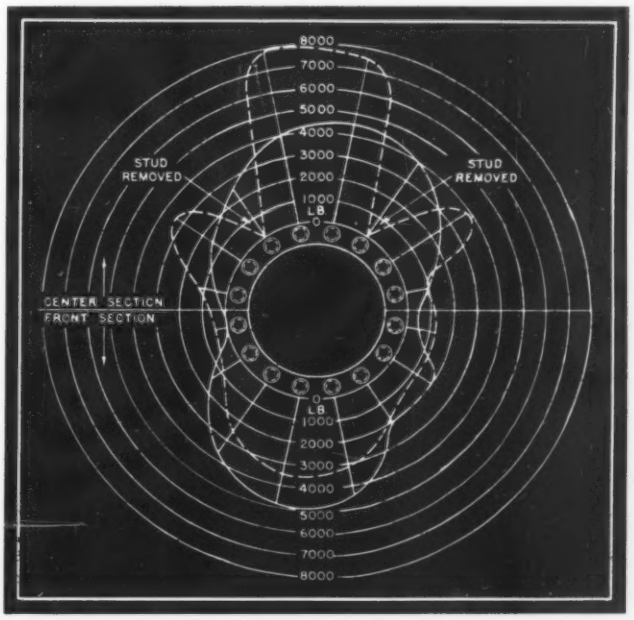

Fig. 6—Load distribution on cylinder hold-down studs is shown for cylinder pressure of 1500 pounds per square inch. Studs are 3/8-inch diameter, 16 NC threads per inch

a stiffener against both flattening and shear. Small steel spools placed at the maximum shear position give the greatest reduction for a minimum increase in pin weight.

Limiting loads which the piston material can withstand are determined by the stress concentrations at the inside of the wristpin boss. Under load the piston dome bends inward causing a concentration of stress at the inner edge of the pin bore. Bending of the wristpin upward has the same effect. Pins of larger diameter which have shorter length sometimes work considerably better even though they have a higher load per unit of projected area. This reduces the amount of bending in the wristpin thus reducing concentration on the edge of the wristpin boss.

Most of the stresses in pistons are of a fatigue nature and pistons should be designed on the basis of the material's fatigue strength at the temperature of operation. Tensile strength and elongation do not seem to enter into the picture except during an engine failure where tensile strength may be considered as a safety factor. The fact that some portions of the piston operate at different temperatures should be carefully considered in determining the stress which that particular part of the piston can withstand. For example, if a piston operates with the bar across the center of the dome at 500 degrees Fahr., it can withstand approximately 5,000 pounds per square inch in reversals of stress at that temperature for indefinite life. If the temperature could be reduced to 400 degrees Fahr., nearly double that load could be carried. In order to tie the static type of testing to operating conditions, a fatigue testing machine is used. It is essentially a hydraulically operated machine which can produce up to 100,000 pounds load in either or both directions between a master piston and a bolster plate at a speed of 1300 cycles per minute. The part to be tested is placed in the machine with its head against a cushion and with an appropriate connecting rod.

Fig. 7—Brittle lacquer coating indicates stress in crankcase due to cylinder pressure of 1500 pounds per square inch

Operating temperatures of the piston are produced by placing electric heaters around the cylinder barrel. Control equipment turns these heaters on and off, holding the test parts at predetermined levels. It is necessary to maintain the same temperature gradients throughout the piston to produce failures comparable to service.

Next major aluminum part is the crankcase. Cast aluminum crankcases have been used since before the first World War. As outputs increased in radial engines, cast material was replaced by forged material due to its higher fatigue strength. While the radial engine manufacturer has been able to make use of forgings, the in-line type of engine does not lend itself to this type of construction.

Avoid Bending Stresses Near Studs

Method of attachment of the cylinder barrel to the crankcase in most cases is by means of studs in the aluminum. Fit of these studs is relatively critical because of the high loads imposed upon them from explosion forces. Studs will operate satisfactorily in the aluminum if care is exercised in their design and assembly. Proper fits and assembly methods have been worked out. In the design of crankcases it is important to be sure that any bending stresses caused by high loads do not occur in the sections in which the studs are located. The load which each stud carries is dependent upon the amount of flexing in the crankcase.

By obtaining the strain in each stud, the distribution around the hold-down circle can be studied. All studs are not uniformly loaded. Load may vary from zero at the parting line of the two cases to a maximum for the studs directly over the diaphragm wall. *Fig.* 6 shows the distribution around this circle as a solid line. Tightening of the hold-down nuts on these studs is especially critical.

To indicate what may happen if two nuts are loose, the dashed line, *Fig.* 6, has been superimposed upon the normal distribution curve in this figure. The loads which the two studs over the diaphragm carry are nearly doubled, indicating an extremely dangerous condition. Methods for improving this distribution include increasing the stiffness of the legs between the cylinder barrels, which forces the studs nearest the parting line to absorb more load, and increasing the flexibility of the diaphragm under the two studs which are most highly stressed.

Rib Design Requires Care

Caution in the use of ribs in crankcases cannot be too highly emphasized. When ribs are used in conjunction with a diaphragm, the ribs take most of the load on their extreme fibers and when thin, round-topped ribs are used, fatigue normally starts at the top of the rib. It would be better use of the metal if ribs only were used, because these ribs could be made broader and stronger. The diaphragm itself, when ribs are used, carries very little of the load and can be made relatively thin. On the other hand, if it is necessary to use a diaphragm type of construction, shallow wide ribs or bars can be used satisfactorily as strengtheners.

Stress distribution tests on crankcases incorporating a ring nut instead of hold-down studs show much better distribution. The ring is similar to that of the German DB-601 engine having threads below the hold-down flange on the barrel and a nut inside the crankcase. *Fig.* 7 shows the stresses in a crankcase produced by 1500 pounds per square inch explosion pressure. The method used employs brittle lacquer in a constant temperature room. Further studies can be made by means of strain gages.

Avoidance of failure due to residual stresses is nowhere more vital than in the welded assemblies of landing barges

Residual Stresses in Welded Structures*

By Robert E. Kinkead

Consulting Engineer, Welding

LIKE most of the problems which arise in connection with electric arc welding, residual stresses may profitably be studied in other forms of metal fabrication. No small part of the difficulties with residual stresses comes about because the practitioner has approached welding with the idea that he would be dealing with something wholly new and so far in advance of anything else that all prior crafts could be neglected. It is questionable whether we shall ever discover anything that does not have its roots in what has gone before.

A steel casting and a welded structure have much in common. The welded structure is steel made by rolling held together by welds which are steel castings. Every kind of erratic behavior in steel castings not stress relieved, has its match in welded steel construction not stress relieved. In both cases the structures squirm when being machined; they crack before getting into service; they virtually explode when subjected to impact in cold weather; they fail with a fracture showing that no plastic deformation took place. The erratic part of it lies in the fact that of two apparently identical structures or castings, one will fail and the other will not. Everyone knows what the steel foundry does to overcome the difficulties—the castings are stress relieved in a furnace, either as an incident to heat treating or as a separate safeguarding operation.

Stress relieving a welded structure in the furnace does in fact prevent erratic behavior from residual stresses incident to welding. If welding procedure has been such as to leave small cracks or extremely high residual stresses, the structure may crack locally in the furnace. This happens also in steel castings and in both cases proper welding repairs may be made.

Three other cases have to be considered: Where the structure is of such a shape as to permit easy mechanical stress relief by loading, where the structure is so large that it cannot be put in a furnace, and where welding techniques are designed to prevent high residual stresses.

A cylindrical or spherical tank of welded components is easy to stress relieve by internal hydraulic pressure in excess of the working pressure, and this method is approved by the ASME Code for certain classes of unfired pressure vessels. Vessels having heavy plate and of a class in which failure might cause death or great destruction require stress relieving in the furnace. Many welded structures for mechanical purposes are effectively stress relieved by loading applied with hydraulic cylinders, by application of weights or by otherwise producing unit stresses greater than the working load. What happens is that metal which is highly stressed incident to the welding operation simply passes through the yield point into the plastic range of deformation, thus dissipating the local residual stresses.

A large oil storage tank, a bridge or a ship represents a structure too large to get into a furnace. Here the solution to the problem of eliminating erratic behavior may be worked out along the same lines that have been proved in pressure vessels. An oil storage tank is required to be filled with water, stressing the structure beyond its normal unit stresses when filled with oil and effectively stress relieving it. A bridge may be loaded with whatever is convenient, water tanks, sand bags, etc. A ship may be loaded with water in her ballast tanks.

Some structures may be stress relieved by their first service loading. This requires the exercise of considerable judgment, where no previous experience with the

*From a paper presented at the recent annual conference of the American Welding society in Cleveland.

type of structure involved is available. The important question which arises, where no previous experience is available, is related to the design of the structure itself and whether residual stresses might cause disastrous failure on first loading. A welded crane girder as now commonly designed illustrates the case of a structure which is not likely to fail on first loading regardless of residual stresses. A poorly designed ship is an example of a structure which may fail on first application of service loading. The temperature at which first loading is applied, whether service loading or for the purpose of stress relieving, will have an important effect. Thus a large crane shovel boom of welded construction given its first loading in zero weather may fail in the plate due to the combination of residual stresses and low-impact resistance of mild steel at low temperatures. There is always a certain amount of

AND LATER, after the gale, there was just as much groaning and straining as ever but it was not so loud or squeaky in tone, and when the ship quivered, she did not jar stiffly, like a poker hit on the floor, but gave with a supple little waggle, like a perfectly balanced golf club . . . .

For when a ship finds herself, all the talking of the separate pieces ceases and melts into one voice, which is the soul of the ship.

—Rudyard Kipling

what might be called snapping and violent readjustment of a welded structure which has not been stress relieved, when the first loading is applied. This sets up impact stresses which, at low temperature in combination with residual and loading stresses, are likely to cause failure.

Using a welding technique to prevent high residual stresses incident to welding is most interesting. Early in the history of welding ships in this country, the Navy adopted a formula for manual welding of ships which has stood the test of time. It is simple: Start welding amidships, weld outboard, fore and aft, up and down, always stepping back. While it is difficult to weld up stepping back toward the centerline—and it is doubtful whether much of it is done—the procedure is sound, and when the additional requirement of keeping the welding balanced on the hull is followed, it works out quite effectively. What the Navy does in terms of loading for stress relief by use of water ballast is information the Navy does not give out.

Stepping back is a procedure which was taken directly from riveting. This practice does effectively limit the degree of transverse residual stress but it does not affect the degree of longitudinal stress incident to the welding operation. Peening weld metal as it is applied and after both weld and plate have returned to ambient temperature is entirely effective in reducing residual stresses. The only valid objection to the practice is its cost.

From the engineering point of view, one would seldom rely for safety on the assumption that any of the procedures designed to prevent or progressively reduce residual stresses had actually done so. There are too many doubts about whether a procedure was followed and the result actually attained. If the structure were of the type which should be stress relieved by loading before any service loading is applied, the load would be applied regardless of the procedure. In this event peening or whatever method was used would be so much waste of time insofar as residual stresses are concerned. Correct procedure and sequence of welding are matters of importance in the welded assembly to prevent cracks, excessive deformation, etc., during the period of fabrication.

In the author's experience, since modern practices have been followed, no structure being stress relieved by mechanical loading at a temperature above 45 degrees Fahr. has failed where the cause could be clearly shown to be primarily residual stresses. Structures fail from other causes under such loading. When the structure fails while being stress relieved no one gets hurt. The break is repaired by welding and retested. A break on such loading has a most salutary effect on the personnel.

Taking into account physical properties of the steel in large structures and those of the weld metal, it is difficult to understand how residual stress could cause failure under static loading. Leaving armor plate out of consideration, weld metal has a higher yield point than steel plate commonly welded.

Mitigates Effect of Impact

Purpose in removing or greatly reducing residual stresses is to protect the structure against failure due to reversal of stress, impact, and erratic behavior due to biaxial and tri-axial stresses. In dealing with the safety of the structure, it is of no consequence whether failure originated in the weld or in the plate which has residual stresses incident to the welding. Unless the structure as a whole behaves under service loading exactly as if it were one piece, its behavior is unpredictable.

It is a fact that no nondestructive method of evaluating residual stresses in a structure is available. Even experience in building a number of identical structures of large size is unreliable. It is never certain that the procedure and sequence were identical. Manner of dealing with residual stresses in welded structures to make the structures safe is based on a vast amount of practical experience in metal working as well as on the experience of large numbers of able men who have built large welded structures successfully for many years.

We are now in the most desperate and frightful struggle in our nation's experience and the need for large welded structures is first on the list of urgency. Vast numbers of new and previously inexperienced personnel serve as workers and as supervisors and even engineers. It is to be expected that errors of judgment will be made. They undoubtedly have been made and will continue to be made. These things are just as unavoidable as the loss of brave and gallant officers and men on the field of battle due to their inexperience as soldiers. The number of failures of large welded structures due to residual stresses, causing loss of life, is so small as to be one of the lowest hazards of the war. The whole story will not be known until after the war is over, and perhaps not then. This general overall picture of methods of dealing with residual stresses is presented in the hope that it will be useful to those who have to take the responsibility of making welded structures safe from failure due to these causes.

Wartime Metallurgy Conserves Strategic Materials

Part XI—Nitriding and Cyaniding

By R. E. Orton and W. F. Carter
Acme Steel Co., Chicago

SURFACES of steels may be brought to a high degree of hardness by impregnating with nitrogen. Aluminum, because of its readiness to form nitrides, is commonly added in amounts from one to 1½ per cent to steels intended for this purpose. Other elements exhibiting this characteristic are also employed, notably chromium and molybdenum. A high-chrome, high-carbon, molybdenum type of tool steel has been so treated for certain applications. Some varieties of austenitic stainless may also be satisfactorily treated.

The action is similar to carburizing, the methane or monoxide being replaced by ammonia gas and temperatures ranging from 900 to 1000 degrees Fahr. being employed. Thus

$$2NH_3 \rightarrow 2N + 3H_2$$

The nascent nitrogen is absorbed by the steel and at once precipitated as the nitride. There is no diffusion after this precipitation, as occurs in carburizing. The nitride, *Fig.* 88, contributes high-hardness and wear quality without the need of a quenching operation. Warpage is thus negligible.

Nitriding times are long, from 48 to 72 hours being required for case depths of .012 to .018-inch with full hardness maintained for only .005 to, at the most, .010-inch of this depth. The first .001 to .002 of the case will generally be slightly softer, and for best wear qualities this should be lapped or ground off. The original nitrided surface has fairly good corrosion resist-

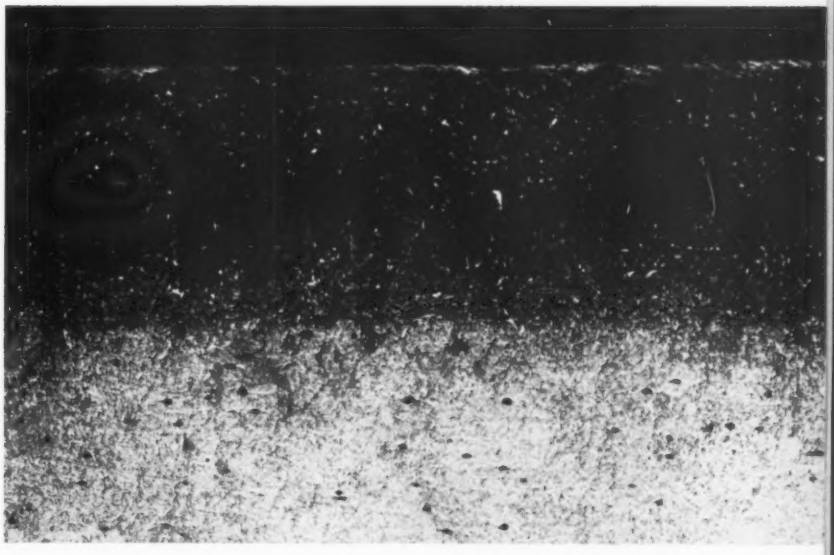

Fig. 88—Above—Typical nitrided case. Nitraloy G steel (C .35, Mn .50, Al 1.15, Cr 1.15, Mo .20). Mangification 75 diameters

Fig. 89—Below—Nitriding of parts for diecasting machine is useful because of the retention of high hardness at casting temperatures

ance against atmosphere and certain types of reagents. When this resistance is desired the surface should *not* be removed. Surface hardness will run up as high as 30N85 superficial rockwell.

The extreme thinness of the case and its inherently brittle nature call for a strong core to support it; thus nitriding steels are practically always alloyed. They are generally heat treated first because a tempered martensitic structure better absorbs the nitrogen and draws back to at least as high a temperature as the nitriding temperature. Since the smallest decarburization results in an extremely brittle case, the heat treating must either be performed in controlled atmosphere or the surface must be machined to remove any decarburization. The steel is frequently purchased as heat-treated bar stock, machined to dimension, and then nitrided. Because it is not practical to "denitride" and reharden, the part either must be to finished dimension when nitrided, or ground to dimension after.

Nitriding produces a highly "fatigue-resistant" case, failures occurring at the junction of the case and core

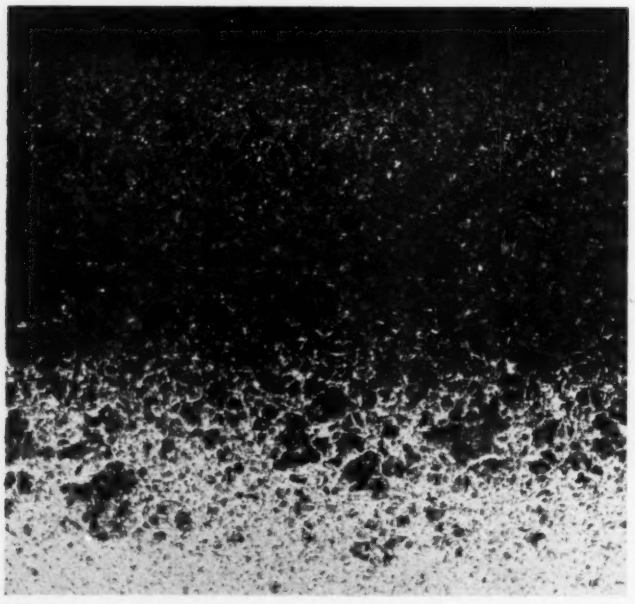

Fig. 90—Typical case structure obtained from liquid carburizers at 1600 degrees. Magnification 75 diameters

rather than at the surface. The treated surface retains its hardness well up into the nitriding range of temperature(2)*.

The nitriding process is particularly adaptable to surfaces calling for the maximum in wear qualities, accompanied by either a very light loading that will not break through the case or a well and uniformly distributed load. Applications include cylinder walls, wrist pins, shaft journals, piston rods, slides, gages, cam followers, etc.(1). *Fig.* 89 illustrates a valuable contribution of nitriding to die casting machine parts. Nitriding is here particularly useful because of the retention of its high hardness at the temperature of the molten die-cast metal. It is also reported that it contributes to the prevention of galling and seizing and has done much to increase the life of these parts.

*References in parentheses are listed at end of article.

Among the remaining processes are the wide varieties of liquid case hardeners. They consist of salts, solid at room temperatures but molten at treating temperatures. Used in general for light cases, up to about .03-inch maximum as a rulle, they range in their alteration of the surface chemistry of the steel all the way from those producing primarily a nitrided surface to those hardening primarily by increasing the carbon content. They all, however, act to do both to a certain degree, the extent of each depending upon their analysis, temperature, and time in the bath.

Case Is Obtained in Short Time

Earliest of these salts is cyanide. Applied in early days as pure potassium or sodium cyanide directly to the hot steel, it is now used in molten bath form. Since the breakdown of the active ingredient is rapid, it is generally diluted with sodium carbonate and chloride—production baths consisting generally of 30 to 50 per cent sodium cyanide. A hard, wear-resistant but superficial case is produced in a relatively short time, about .01-inch thick in one hour; holding beyond this time produces only a slow increase in case depth.

Cyanide reacts with the oxygen of the air to release nascent nitrogen and carbon monoxide:

$$2NaCN + 2O_2 \rightarrow Na_2CO_3 + CO + 2N$$

The nascent nitrogen is absorbed by the steel as in nitriding and the CO reacts to release C as in carburizing, the resultant case being a composite structure. Bath temperatures range from 1450 degrees to 1600 degrees, the lower temperature favoring higher N to C ratios, and the higher the reverse. Surface carbon will generally only be .5 to .7 per cent, the hardness being primarily due to the N, the carburized portion acting more as a support. The nitrogen is even more superficial than the C, generally dropping off in a few thousandths of an inch from the surface.

Quenching is almost always directly from the pot, being in water or oil according to the dictate of the application. Water is probably the more common as it results in cleaner work. The case is generally brittle, and the process is only applicable where the surface is lightly

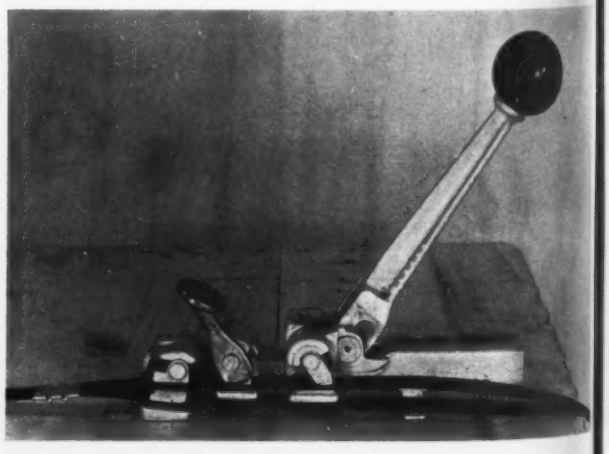

Fig. 91—Use of a liquid carburizer and a low-carbon, unalloyed steel for the gripping dogs of this strapping tool saves critical tool steel

loaded. It may be applied to high-carbon or carburized steels but, if carbon content is high with both cyanide and temperature low, it may decarburize the surface somewhat. The process has been applied to many of the parts to which nitriding is applicable. It is fast and cheap, being therefore well adapted to small screws, washers and pins, locating blocks and bushings on fixtures and dies, gages, etc.

Results Vary Widely

Cyanide baths have been used to produce light-nitrided surfaces by running up the cyanide content and operating at 1000 to 1100 degrees. Practically no carburizing occurs at this temperature. Usual practice is about 30 minutes at temperature, although sufficient hardness to prevent galling and seizing on gages, etc., will be obtained in about five minutes. The practice has been followed on high-speed steel, "high-chrome, high-carbon" die tool steel, and others that resist the tempering action of the salt. It is applied, in particular, to sharp edge cutting tools such as taps, chasers, broaches, reamers, etc.(16), and to gages, small pins and other light wearing parts.

Field reports vary widely, some showing enormous increases in the life of such tools, and others reporting chipping trouble with little gain in wear. It would appear that if everything is just right, a great deal is gained; but if the least thing is out of order—decarbed surface, a blow on the tool, perhaps a balled up chip or a hard spot—failure occurs. Experience in the authors' plant has been equally contradictory and no satisfactory conclusions have been drawn.

Passing mention should be made here of a process for "dry cyaniding"(17). It consists of introducing ammonia

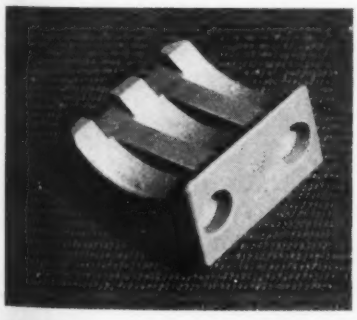

Fig. 92—Use of low-carbon, free machining steel permits the economical manufacture of small parts such as this. Liquid carburizing provides a thin case with wear qualities

gas into the furnace atmosphere in gas carburizing. Results similar to liquid cyaniding are produced, the case being a combination of nitrogen and carbon.

While nitrides contribute fine wear qualities, they produce too brittle a case for many applications. Because of this and to secure heavier cases, activating catalysts consisting primarily of barium and calcium cyanamides are introduced. Cyanamides act to increase the carbon to nitrogen ratio, resulting in deeper cases, higher in carbon and lower in nitrogen.

By increasing the quantity of cyanamide and reducing the sodium cyanide to 10 to 20 per cent, the so-called "liquid carburizer" is obtained. A carbon "blanket" is also added to the top of the bath, formed by adding graphite or from carbon leaving the bath. This blanket acts to reduce markedly the heat radiation and to check also the cyanide breakdown by keeping the oxygen from the atmosphere from readily contacting the bath. Case depths of .05 and deeper are practical, although usual practice is to develop .03 or under. The case, *Fig.* 90, will have a relatively small amount of nitride for a few thousandths below the surface, and will have carbon contents varying from 1.2 per cent to somewhat below the eutectoid, depending upon salt analysis and operating temperature, with carbon well maintained in depth, and showing a good blending with the core.

The bath analysis may be readily controlled. Rate of breakdown is such as to make its use feasible for intermittent work. Heating is rapid, and light cases may be obtained in an hour or two. By running samples along

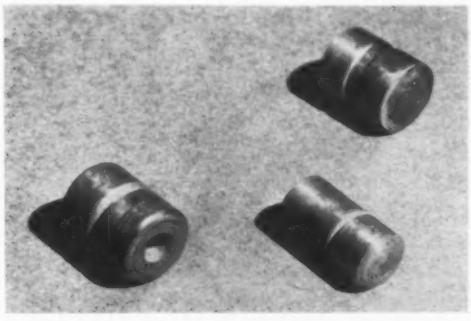

Fig. 93—Rolls for cold edging of strip steel. Formerly nitrided alloy steel, successful substitution is SAE X-1020, liquid carburized

with the load excellent control may be had of the case depth, making the method suitable for the casing of light sections. Work is generally self-cleaning on water quenches, and, if analysis is properly maintained, oil quenches may be readily rinsed off in a hot water bath or spray. Method is particularly well adapted for handling small parts by suspending in a basket, *Fig.* 60*, and dumping from the basket into the quench.

Effects Permanent Substitution

The combination of nitrogen and carbon obtained by these hardening agents makes a particularly suitable replacement for many wartime substitutions. *Fig.* 91 shows gripping dogs, made in large quantities for this company's strapping machines and tools, formerly made from 1½ per cent carbon, 12 per cent chrome die steel, replaced by SAE X-1020, liquid carburized .015 deep at 1600 degrees, water quenched and drawn at 250 degrees Fahr. for a hardness of rockwell A-83. Tests on a pilot lot, and preliminary reports from production lots in the field, indicate wear qualities at least as good as, possibly better than, those obtained from the replaced material. In addition to saving a considerable amount of strategic alloy and tool steel capacity for the war program, machining speeds were greatly increased with a better finished surface. Production costs were halved by this "permanent substitution".

Advantages that may be obtained by the use of liquid carburizers are illustrated in *Fig.* 92. This small and intricate part is free machining steel using a cold-drawn

*Part VII, MACHINE DESIGN, Feb. 1943, Page 113.

stock size close to the overall dimension. The ease of manufacture obtained by this type steel together with the use of a stock size close to dimension greatly reduces the cost of production of this part over that of a through hardening steel. A case .005 to .010-inch deep obtained with liquid carburizing provides the wear qualities required.

Fig. 93 shows rolls for cold edging of strip steel—formerly made from a nitralloy with 72-hour nitriding—now liquid carburized, with equal wear life, much lower production cost, and an appreciable conservation of strategic materials.

Carburizing salt bath is satisfactory for reheating steels for quenching or for special rush quantities of through hardening. If the small casing that will be obtained in the short time is not objectionable the bath may be used as is, otherwise the cyanide content should be allowed to drop, producing an essentially "neutral" salt. An excellent practice on heavy fixture and die locating blocks, where the equipment is available, is to carburize .03 to .05 in the gas carburizer, slow cool, straighten if necessary, machine any portions not desired hard, and reheat in salt furnace, quenching in brine as soon as part is at temperature. Quenching in this way the core will still be at a low temperature and will restrain further warpage. Case will be refined at same time and will pick up a slight nitrogen content, increasing abrasion resistance. Total distortion, by this practice, may be kept within a few thousandths. Parts should preferably be tempered at 200 to 350 degrees to relieve quenching stresses.

A certain amount of growth occurs at the surface of all case-hardened material This will, in general, result in the closing in of holes, enlarging of pin diameters, etc. It must either be removed after heat treating or allowed for in the machining operations. The amount will vary with the material, temperature, carburizing medium, etc. As an example, on SAE X-1020 in liquid carburizer at 1550 degrees Fahr. for .03 case, an increase of .0005 to .00075 per surface on oil quench and up to .001 on water can be expected.

The preceding discussion is not intended either to be comprehensive as to all the methods of case hardening, nor lengthy in its discussion of each method. For extensive discussions the selected references appended are recommended.

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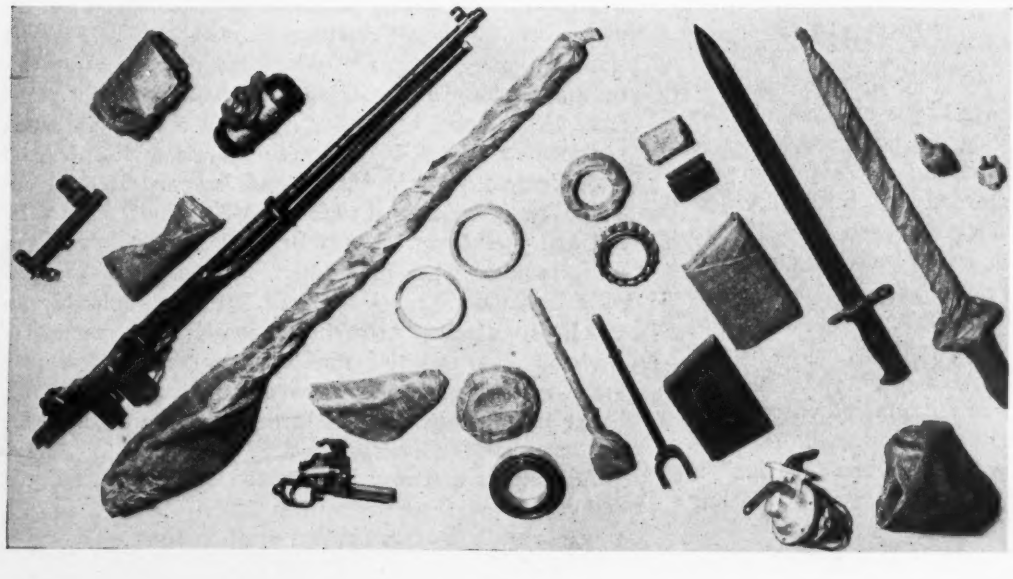
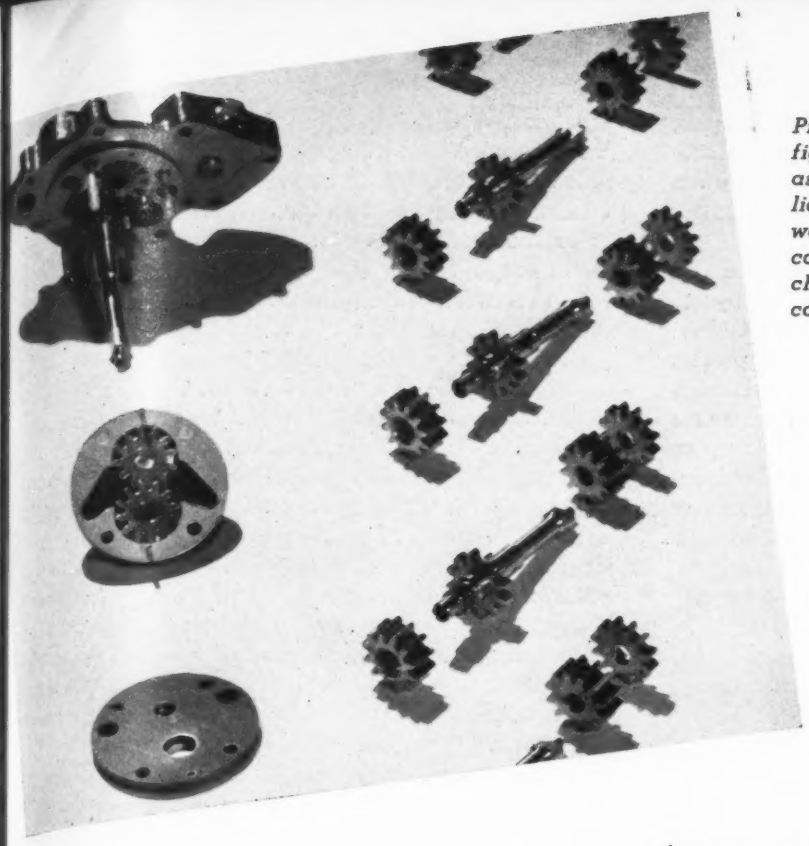
Protects Ordnance Parts

GREASEPROOF wrappings for ordnance and machine parts facilitate handling of supplies for overseas shipment or storage. To prevent corrosion under extreme weather conditions and transportation difficulties, parts are either greased or slushed with a rust preventive and wrapped with a paper designed to hold the rust preventive on the metal surface to which it has been applied. Paper wrappings shown at left, developed by Dennison Manufacturing Co., have a limp, dead-fold quality which, combined with a degree of adhesion, allow the wrappings to conform to the contour of an irregular-shaped object without much danger of tearing or puncturing on corners of the parts.





Proposed redesigns for fighter plane parts such as these fuel pumps for liquid - cooled engines would have to include consideration of interchangeability — Photos courtesy General Motors

How the Army Approves Redesigns

***PROCEDURE** to be followed in securing approval for redesigns or specification changes on army air force and ordnance contracts is explained in the accompanying articles which are based on lectures presented at a recent meeting of the Metropolitan Chapter of the American Foundrymen's Association. Supplementing the article "Worried About Specifications? Here's Washington Answer," which appeared in the May issue of MACHINE DESIGN, the authors describe the machinery for submitting and approving changes deemed essential in the interests of increased production or of conservation of scarce materials*

Approving Redesigns on Air Force Contracts

By E. C. Duval
Chief, Materiel Conservation Section
Wright Field

PROCUREMENT activities of the A.A.F. are grouped into four geographical districts. Each district office, which is a part of the Materiel Command at Wright Field, Dayton, Ohio, is provided with a Production Engineering section authorized to make engineering decisions involving aircraft or aeronautical equipment where such decisions do not affect interchangeability, safety, cost or delay in handling of items concerned and where prompt decision is necessary to prevent delay in production or delivery. This section maintains contact with manufacturers through A.A.F. area officers, resident representatives, and inspectors in charge at the various plants. It should be noted that contact with any of these people is actually contact with a representative of Wright Field.

The production necessary to meet war needs has necessitated much redesign of equipment used by the A.A.F. The small quantities procured in peacetime and the rapidity of new developments do not warrant the employment of progressive stamping dies, forgings and automatic single-purpose machines. Peacetime designs must, of necessity, be compromises which may be used in time of war until they can be revised for quantity production and adapted to the latest shop practices.

In general, requests for approval of redesigns developed by contractors working on A.A.F. contracts should be submitted through the most immediately available representative of the Materiel Center of the A.A.F. In the case of large prime contractors manufacturing airframes, engines, propellers, etc., a commissioned officer of the Materiel Command is stationed at the prime contractor's plant as a resident representative to handle all matters concerning the prime contractor. In such cases

complete data—which may consist of blue prints, samples, test reports, or, in simple cases such as change of material, a letter or wire—covering the proposed redesign are forwarded to the District Production Engineering officer through the A.A.F. inspector.

Design modifications not within the scope of the district production engineering section are submitted by the district office, after examination, to the Materiel Center, Wright Field, for approval. As a general rule the process of securing a deviation for the use of a beneficial redesign is relatively simple. While consideration must of course be given to the retention of existing designs for the sake of interchangeability, approval will be granted if the desired end warrants. In special cases exhaustive tests may be necessary before approval can be given for changes in structural or other highly stressed parts.

Specifications covering articles of equipment to be supplied operating services are in most cases strictly performance specifications setting up the end requirements for the equipment. Manufacturers design each particular article to meet these requirements and are responsible for the materials employed to meet the performance and tests outlined in the specification. In such cases changes proposed by the manufacturer, backed by sufficient test data to prove that the article still meets the performance requirements, are usually approved in a short time.

Cylinder heads for air-cooled engines meet exacting conditions. Redesign to expedite production has also resulted in improved performance

Procedure Is Explained

Where interchangeability is likely to be affected, a "change notice" is prepared at the time a proposed redesign is submitted and six copies forwarded to the Commanding General, Air Service Command, Patterson Field, Fairfield, Ohio, Attention: Maintenance Division, Change Notice Unit. A seventh copy of the change notice is forwarded with the engineering proposal covering the change to Materiel Command, Wright Field. This proposal and change notice are reviewed by the engineers responsible for the development and test of the particular article and a decision arrived at as to the desirability of the change. When a change is approved the approval is sent back to the district office which in turn notifies the contractor to proceed with the change. If a change order or amendment to the contract is necessary this will follow through the contract section at Wright Field but actual execution of the change in the manufacturer's plant need not be held up until these legal procedures are completed.

Purpose of the change notice to the Commanding General, A.S.C., is to provide the Air Service Command, which is responsible for maintenance of airplanes and field use, with sufficient preliminary information concerning the change which the contractor contemplates to enable a decision to be made regarding the desirability of the change on delivered equipment. The notice also provides information on revisions which may require a change in maintenance tools, handbooks of operation, or service instructions for the particular article concerned. Were it not for this procedure, changes might be made which would affect service in the field and of which field maintenance crews might not be cognizant.

Submission of the change notice to the Air Service Command concurrently with the submission of the engineering proposal through the district production engineering section sets up machinery for determination of the total number of the changed parts required for maintenance and possible field replacement as well as for incorporation in production articles.

Fresh Viewpoint Inspires Redesign

Inasmuch as most of our aircraft designers learned their trade during an era of abundance when the cost of the best materials was relatively small compared with the overall cost of the particular article, many designs specify materials and manufacturing methods of the highest quality. By contrast our enemies have had to work out their designs from the standpoint of using the fewest quality materials, making inferior substitutes suffice wherever possible. We find every day that intelligent appraisal of many articles now in production has resulted in the substitution of readily available materials for scarce materials, in simplification of manufacturing techniques and of design as a result of a fresh point of view.

In a typical case which occurred recently, a manufacturer of a hydraulic landing gear strut found that the design was not adapted to quantity production. The parts were difficult to machine and assembly was tedious and required considerable skill. The manufacturer attacked the problem from the standpoint of redesign and worked out a "cleaned-up" design which reduced the total number of parts and vastly simplified manufacturing and assembly problems. The simplification of assembly will obviously be of great help to mechanics who must service and repair this type of strut in the field.

Cases occur right along where a manufacturer has been producing articles for years with perfect satisfaction to himself and the government but suddenly finds that when he attempts large scale production, tools wear out with a rapidity out of all proportion to the quantity of parts produced. A change in material has cured the evil in many cases, the resulting article serving its purpose with complete satisfaction.

It is suggested that wherever possible those who are associated with firms manufacturing articles for the A.A.F. keep in mind that there is nothing sacred about the designs on which they are working. However, it must be borne in mind that equipment has to be serviced in all parts of the world under all conditions and in many cases by personnel not too familiar with it. It is a most difficult task to have the necessary instructions at hand for repair when and where it is needed. Changes which may be of advantage from the manufacturing end but affect interchangeability of parts should be viewed with respect to their effect on the repair of the equipment in a foreign country and under adverse conditions. It is recognized that many designs can be improved with profit to all concerned, as was the case with the shock strut already mentioned and, when the results warrant the change, approval will be given as promptly as possible depending upon the tests, if any, required to prove the new design.

Prime Design Contractor Is Ultimately Responsible

Those who are functioning as subcontractors should, of course, refer suggested redesigns to the A.A.F. through the contractor who holds the prime design contract. Prime contractors working on a licensee basis must also submit their suggestions to the prime design contractor as he is responsible for the performance of the articles constructed in accordance with his drawings and specifications. In all such cases the prime design contractor is responsible for obtaining approval of the changes.

The necessity for conservation of materials has been the cause of many redesigns and undoubtedly will continue to be as emergencies develop. The Materiel Conservation section was established as a clearing house for all matters connected with conservation about a year ago, although conservation was a pertinent question with all engineers and others connected with development work for a considerable period of time prior to that.

It has been found that critical materials can be conserved in two general ways—by the substitution of less critical materials, which often entails changes in design, and by changes in manufacturing processes. The first method has received special attention up to the present time but it is firmly believed that much more material can be conserved by more efficient manufacturing methods. A great deal of effort is being expended toward this end at the present time and increased emphasis is to be placed upon this in the future. Several cases have been brought to the attention of the office in the past few months where scrap on high-grade materials has been reduced from above 90 per cent to less than 10 per cent by changing from a forging to a stamping. Such a change not only saves material but permits machines to be put to other uses and employs presses which otherwise would be idle. Many such changes have been made without affecting the interchangeability of parts in any way and every encouragement is given to the manufacturer to work out such ideas whether he has a contract with the government or not.

Inspectors and A.A.F. representatives, who are in the plants daily, are encouraged to report processes which are wasteful of material. They may not have time themselves to formulate a recommendation as to a better method but all such cases are put in the hands of competent personnel to investigate and to see if more economical processes cannot be worked out. This is not a criticism of the designer or manufacturer but it is a condition brought about, as previously mentioned, because designs must naturally be revised to meet present conditions. The revised facts must in many cases be produced by another manufacturer who has the proper equipment which might otherwise be idle. This is usually satisfactory to the contractor who is producing the complete article.

A third method of conserving critical materials has been employed effectively in several cases where large quantities of high grade scrap are generated in normal manufacturing operations. This is by properly segregating the material and channeling it back into the production line for a specific purpose. This material is returned to the producer, such as a steel mill, where it is melted and returned to the manufacturer as a part of his order for raw stock. This has, in some cases, completely eliminated the threatened shortage of material for certain products and is encouraged wherever feasible.

Expediting Army Ordnance Approvals

By T. J. Little
Conversion Engineering Section
New York Ordnance District

ONE of the War Department's largest purchasing agencies is the Army Ordnance department. It is responsible for the procurement of all items of ammunition, weapons and fire control equipment used by the Army, as well as combat and cargo vehicles and packing accessories used for the shipment and storage of such materiel.

High - grade scrap generated in production of parts such as these valve tappet guides for air-cooled engines can be returned direct to producer for melting and return

In general the Ordnance Department is divided into five main branches or sections, namely—Ammunition, Artillery, Small Arms, Miscellaneous, and Tank and Automotive. The magnitude of the present Ordnance procurement program can be appreciated when thought is

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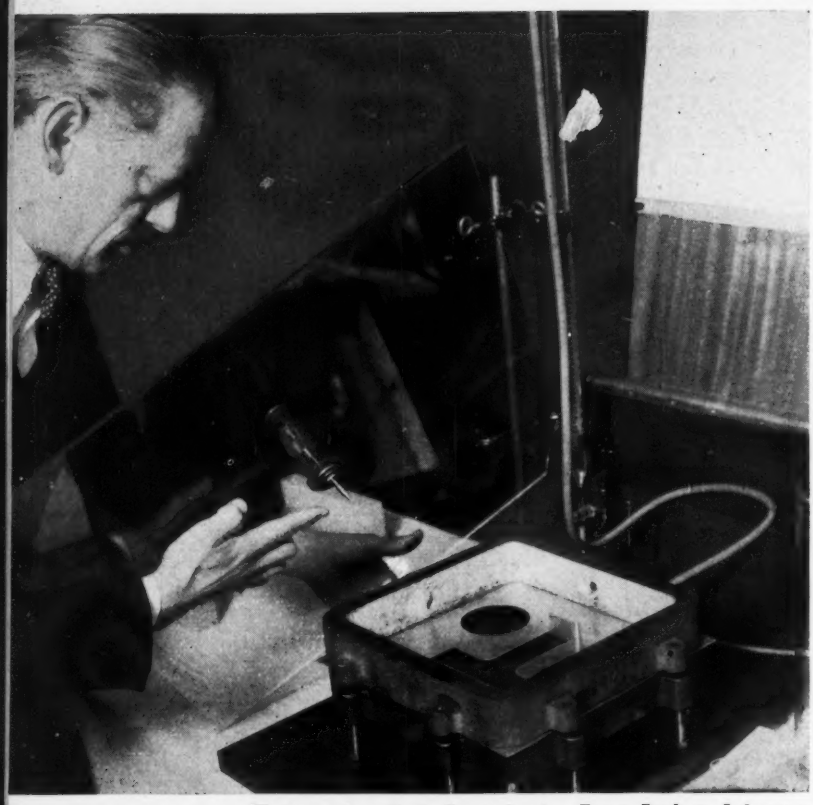

—Photo courtesy U. S. Forest Service, Forest Products Laboratory

Fig. 1 — Membrane - analogy apparatus assists in determining stresses in noncircular machine parts

Evaluating Torsional Stresses by Membrane Analogy

By Joseph Marin
Pennsylvania State College

THEORETICAL methods of stress analysis have been developed to determine torsional stresses in members of circular, elliptical, rectangular, and triangular cross section. For members with other cross-sectional shapes, either an approximate or experimental method must be used to determine the torsional stresses since the theory of elasticity is inadequate for this purpose. Members of irregular cross section subject to torsional moments are encountered in various machines, structures and aircraft. Sometimes the critical part is an irregularity and if available test results for such members are not satisfactory an experimental study must be made.

A *direct method* of determining torsional stresses experimentally is often used. In this procedure a pure twisting moment is applied to the ends of the member and the angle of twist corresponding to increments of torque is observed. From these data the yield and ultimate twisting moments are found. In some cases it is important to determine the points of maximum stress. For this purpose extensometers of various types can be used to determine the deformations on the surfaces, from which the stresses can be calculated. Sometimes the critical points have been observed by coating the surface with whitewash or "stress coat". For example, strain measurements were made in the study of torsional stresses in H and I structural steel beams by Lyse and Johnston(1)*. Direct reading extensometers and a coating of whitewash to indicate yielding were used in these tests. Gadd and Van Degrift(2) determined torsional stresses in fillets of crankshafts by using specially designed extensometers.

Indirect methods for obtaining torsional stresses are based on analogies between the stress problem and other physical phenomena. An electrical analogy was developed by Jacobsen(3) for determining the stresses in circular shafts of variable cross section. Stresses at the changes in cross section were studied and fillets of various radii considered. The model used was a steel plate, the form of the outline being that of one-half the longitudinal section of the shaft. That is, one of the longitudinal edges of the model corresponded to the central axis of the shaft. Thickness of the model was made to vary as the cube of the distance from the edge corresponding to the shaft center line. By constructing the model in this manner it can be shown mathematically that the differential equations for the flow of electricity in the model have the same form as the differential equations of elasticity for the torsional stresses in the corresponding shaft. In this method the drop in electrical potential between any two points on the model is measured by means of a sensitive galvanometer. From measurements of the drop in electrical potential the stresses can be determined at various points on the fillet. The electrical analogy method has also been used to determine stresses in models of bridge trusses.

A *hydrodynamic analogy*(4) is useful in analyzing torsional stresses in members with re-entrant corners or other sharp irregularities producing stress concentration. Such irregularities are produced by longitudinal holes or keyways. It is found that the problem of the twisting of bars of uniform cross section is mathematically identical to that of the motion of a frictionless fluid moving with

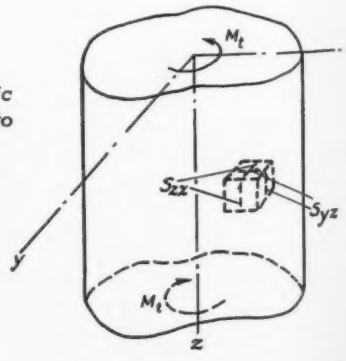

Fig. 2 — Prismatic member subject to torsion stresses

*References are listed at end of article.

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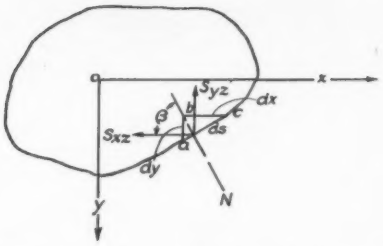


Fig. 4—Above—Representation of boundary stresses

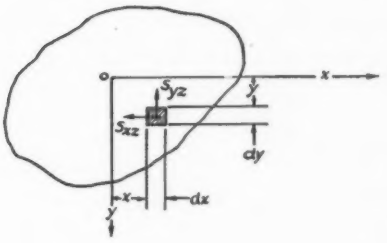


Fig. 5 — Right — Stresses at end of member

a uniform angular velocity inside a cylindrical shell having the same cross section as the bar. The velocity of the circulating fluid at any point corresponds to the shearing stress at the same point in the twisted bar. If a discontinuity such as a keyway is introduced in a shaft, the analogous hydrodynamic model will show increased velocities of flow at the point of stress concentration. This method is useful in studying torsion problems qualitatively.

The *membrane* or *soap-film analogy*, has been used more than the foregoing procedures in the study of torsional stresses. This analogy was first discovered by Prandtl(5). Its basis is that the differential equation for the stress function in torsion is similar in form to the equation for the shape taken by a film under lateral pressure when stretched over an opening representing the cross section of the member, *Fig.* 1. To discuss the basis of this method it will be necessary first to consider the general theory of torsion. Aside from the usefulness of this procedure as an experimental tool, it is valuable in making possible the approximate theoretical solution of many problems. This approximate procedure will also be explained in the following.

Theory of Torsion

General solution for the torsional stresses in prismatic bars of constant cross section subject to twisting couples at their ends was developed by St. Venant(6). *Fig.* 2 represents a prismatic member subject to end twisting moments M_t. For members of circular cross section, a plane cross section perpendicular to the longitudinal axis z remains a plane after twisting. This condition simplifies the solution for the case of a circular cross section. It is, however, an assumption which does not hold for noncircular cross sections.

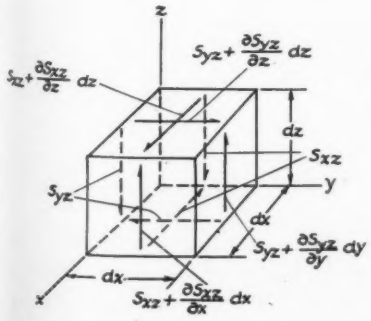


Fig. 3 — Variation of shear stresses on element

To determine the shear stresses in the general case, the stress components for the element in *Fig.* 2 are shown in *Fig.* 3. The shear stresses S_{xz} and S_{yz} are assumed to be the only stress components. These stresses vary in magnitude in the x and y directions, as shown in *Fig.* 3. Writing the equations of equilibrium in the x, y and z directions for *Fig.* 3,

$$\frac{\partial S_{xz}}{\partial z}=0,\ \frac{\partial S_{yz}}{\partial z}=0,\ \text{and}\ \frac{\partial S_{xz}}{\partial x}+\frac{\partial S_{yz}}{\partial y}=0 \quad \ldots\ldots\ldots\ldots (a)$$

The first two of these equations state that there is no variation in the stresses with respect to the longitudinal axis z and hence the stress distribution is the same for all cross sections. The stress distribution must therefore be such as to satisfy the third equation in order to satisfy the equilibrium condition. In stating this condition it is convenient to introduce a stress function ϕ related to the stresses S_{xz} and S_{yz} by the following equations:

$$S_{xz}=\frac{\partial \phi}{\partial y},\ S_{yz}=-\frac{\partial \phi}{\partial x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

By so selecting the stresses, the third equation of equilibrium of Equations a is satisfied. If the stress function ϕ is known, the stresses are defined by Equations 1. To determine an equation for the stress function it is necessary to consider the deformations produced and to formulate the continuity conditions as in other statically indeterminate problems of elasticity. This is done by considering the geometry of the deformations in the element of *Fig.* 3 and by using the relations between stress and strain as given by Hooke's law(7). In this way the equations of continuity reduce to

$$\frac{\partial^2 S_{yz}}{\partial x^2}+\frac{\partial^2 S_{yz}}{\partial y^2}=0,\ \frac{\partial^2 S_{xz}}{\partial x^2}+\frac{\partial^2 S_{xz}}{\partial y^2}=0 \quad \ldots\ldots\ldots\ldots\ldots (b)$$

By substituting values of S_{yz} and S_{xz} from Equation 1 in Equation b,

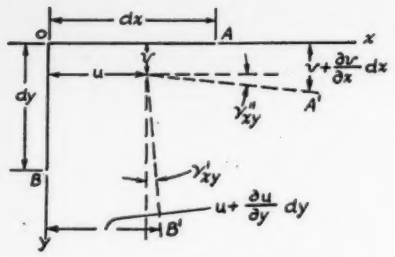


Fig. 6 — Deformation of element

$$\frac{\partial}{\partial x}\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}\right)=0,\quad \frac{\partial}{\partial y}\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}\right)=0 \quad \ldots\ldots (c)$$

These two equations are satisfied provided the quantity in the brackets is a constant. That is, calling this constant R,

$$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}=R \quad \ldots\ldots (2)$$

This means that the stress function selected for a particular cross section must satisfy Equation 2 if the conditions of equilibrium and continuity are to be realized. In addition, it is necessary to consider the boundary conditions of the member. Since the member is free from external forces on the lateral surfaces, the resultant force normal to the surface in the direction N, *Fig.* 4, must be zero, or

$$S_{zz}\cos\beta - S_{yz}\sin\beta = 0 \quad \ldots\ldots (d)$$

Placing the values of the stresses from Equation 1 in Equation d and noting that $\cos\beta = dy/ds$ and $\sin\beta = dx/ds$,

$$\frac{\partial\phi}{\partial y}\frac{dy}{ds}+\frac{\partial\phi}{\partial x}\frac{dx}{ds}=0 \text{ or } \frac{d\phi}{ds}=0 \quad \ldots\ldots (3)$$

Equation 3 states that there is no change in ϕ with respect to s. That is, *the stress function ϕ is constant along the boundary.* For singly connected boundaries the ϕ value at the boundary will be arbitrarily taken as zero. Another required boundary condition is that at the ends there must be a pure twisting moment. Hence the summation of the stresses in the x and y directions is zero. That is,

$$\int\int S_{zz}dxdy=0,\ \int\int S_{yz}dxdy=0 \quad \ldots\ldots (e)$$

Substituting values of the stresses from Equation 1 in Equation e and noting that ϕ is zero on the boundary of the cross section, it is found that Equations e are satisfied. The moments of the stresses about the z axis must equal the applied twisting moment M_t. That is, from *Fig.* 5,

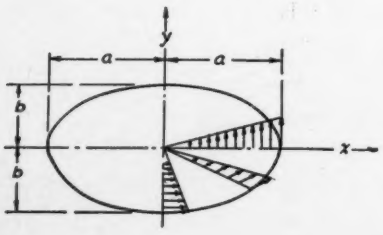


Fig. 7 — Stress distribution for an elliptical section

$$M_t=\int\int(S_{yz}x-S_{zz}y)dxdy=2\int\int\phi dxdy \quad \ldots\ldots (4)$$

The foregoing analysis shows that the stress components are given by Equation 1 in terms of a stress function ϕ which must satisfy Equation 2 and be zero at the boundary.

To determine the deformation of a member, as measured by the angle of twist θ, it is necessary to consider the strain components for the three-dimensional case of stress. If u, v and w represent the total strain components for a point in the directions of the x, y and z axes, then the unit strain values in terms of u, v and w are

$$\left.\begin{aligned}&\epsilon_x=\frac{\partial u}{\partial x},\quad \epsilon_y=\frac{\partial v}{\partial y},\quad \epsilon_z=\frac{\partial w}{\partial z}\\ &\gamma_{xy}=\frac{\partial u}{\partial v}+\frac{\partial v}{\partial x},\quad \gamma_{xz}=\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x},\quad \gamma_{yz}=\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\end{aligned}\right\} \quad \ldots (f)$$

The foregoing equations for the unit strains are based on the geometry of the deformations. Considering the deformation of a differential element, *Fig.* 6, in the xy plane, the sides OB and OA deform to $O'B'$ and $O'A'$. Then the unit deformation ϵ_x in the x direction is $\partial u/\partial x$

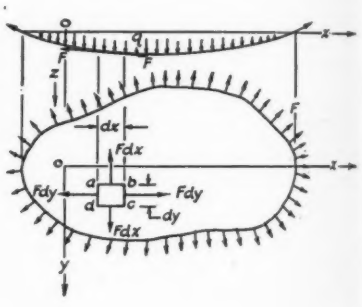


Fig. 8 — Loaded membrane

and the unit deformation ϵ_y in the y direction is $\partial v/\partial y$. The angular shearing deformation γ_{xy} is the sum of the angles γ'_{xy} and γ''_{xy} as given in Equations f. In a similar manner the other unit deformations given in Equations f can be determined by considering the deformations in the xz and zy planes.

In the problem of torsion the first three strains representing the normal strains are zero since the normal stresses are zero. Then it follows that the shearing strain γ_{xy} is zero. There remain, therefore, only the shearing strains γ_{xz} and γ_{yz} which, by Hooke's law, are

$$\gamma_{xz}=\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}=\frac{S_{xz}}{G},\quad \gamma_{yz}=\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}=\frac{S_{yz}}{G} \quad \ldots\ldots (g)$$

The first four of Equations f are satisfied if values of the deformations u and v are selected such that

$$u=-\theta yz \text{ and } v=\theta xz \quad \ldots\ldots (h)$$

where θ is the angle of twist per unit length of the bar.

To determine the value of the angle of twist θ, the first of Equations g is differentiated with respect to y and the second with respect to x and subtracted one from the other. This gives

$$\frac{\partial}{\partial z}\left(\frac{\partial u}{\partial y}-\frac{\partial v}{\partial x}\right)=\frac{1}{G}\left(\frac{\partial S_{zz}}{\partial y}-\frac{\partial S_{yz}}{\partial x}\right) \quad \ldots\ldots (i)$$

Placing the values of the deformations from Equations h in Equation i,

$$-2G\theta=\frac{\partial S_{zz}}{\partial y}-\frac{\partial S_{yz}}{\partial x} \quad \ldots\ldots (j)$$

Using the values of the stresses in terms of the stress function ϕ (Equation 1), the angle of twist θ in terms of ϕ is, from Equation j,

$$-2G\theta=\frac{\partial^2\phi}{\partial y^2}+\frac{\partial^2\phi}{\partial x^2} \quad \ldots\ldots (5)$$

The angle of twist in a prismatic bar subject to a twisting moment can be determined now provided the stress function ϕ is known. Then the value of the constant R in Equation 2 can be shown to have a simple meaning. By comparing Equations 2 and 5 the value of R is

$$R=-2G\theta \quad \ldots\ldots (6)$$

To determine the angle of twist and the shearing stresses it is necessary to determine the correct stress function ϕ such that the equation of compatibility, Equation 2, and the boundary condition of Equation 4 are satisfied. In addition, the stress function must be zero at the boundary as stated by Equation 3. Then the shearing stresses are given by Equations 1 and the angle of twist by Equation 5. Determination of these stresses and angle of twist will be illustrated by the following example.

EXAMPLE—TWISTING OF A BAR WITH ELLIPTICAL CROSS SECTION: The boundary of a cross section with an elliptical contour is given by the equation

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}-1=0 \quad \ldots\ldots (k)$$

The cross section, as shown in *Fig.* 7, has minor and major axes b and a. A stress function that will satisfy the Compatibility Equation 2 and be zero at the boundary, as required by Equation 3, is

$$\phi=m\left(\frac{x^2}{a^2}+\frac{y^2}{b^2}-1\right) \quad \ldots\ldots (l)$$

where m is a constant.

Value of m is obtained by placing ϕ from Equation l in Equation 2. This shows that its value must be

$$m=\frac{a^2b^2}{2(a^2+b^2)}R \quad \ldots\ldots (m)$$

The value of ϕ in terms of R is given by substituting the value of m from Equation m in Equation l. That is,

$$\phi=\frac{a^2b^2}{2(a^2+b^2)}R\left(\frac{x^2}{a^2}+\frac{y^2}{b^2}-1\right) \quad \ldots\ldots (n)$$

The value of R in this equation can be found from the boundary condition of Equation 4. Using the foregoing value of ϕ in this equation,

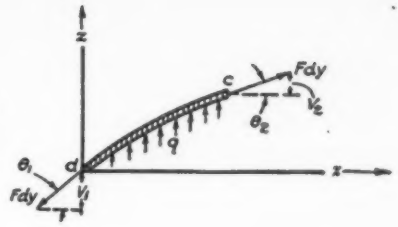


Fig. 9—Forces on membrane element

$$M^t=2\int\int\phi dxdy=-\frac{\pi a^3b^3R}{2(a^2+b^2)}$$

or

$$R=-\frac{2M_t(a^2+b^2)}{\pi a^3b^3} \quad \ldots\ldots (o)$$

The stress function ϕ is now completely defined by placing the value of R from Equation o in Equation n. This gives

$$\phi=-\frac{M^t}{\pi ab}\left(\frac{x^2}{a^2}+\frac{y^2}{b^2}-1\right) \quad \ldots\ldots (p)$$

With the stress function ϕ determined, the values of the stresses are found from Equations 1 and the angle of twist from Equation 6. Their values are

$$S_{zz}=-\frac{2M_ty}{\pi ab^3}, \quad S_{yz}=\frac{2M_tx}{\pi a^3b} \quad \ldots\ldots (7)$$

$$\theta=M_t\frac{a^2+b^2}{\pi a^3b^3G} \quad \ldots\ldots (8)$$

Placing $a=b=r$, the above formulas coincide with the well-known equations for the circular cross section.

Unfortunately this theoretical method can be used only for a few cross-sectional shapes. In all other cases an experimental procedure must be used. The foregoing general theory for torsion is necessary, however, in explaining the basis of the membrane or soap-film method.

Membrane Analogy Method

As previously mentioned, this method is based on the fact that the differential equation of the stress function is of the same form as the differential equation of a film when stretched over an opening of the shape of the cross section and subjected to a lateral pressure. The

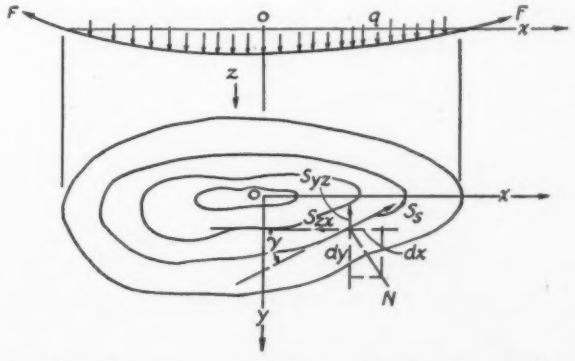


Fig. 10—Membrane deflection and plan representation by contours

equation of this film will be determined first.

For this, a homogeneous membrane may be imagined as supported at the edges and with the same outline as the cross section of the twisted bar. Considering that this membrane is subjected to a uniform lateral pressure as shown in *Fig.* 8 and letting q be the pressure per unit area of the membrane and F be the uniform tension per unit length of its boundary, the forces acting on the free body diagram of the element *abcd* of *Fig.* 8 are shown in *Fig.* 9. If the deflections of the membrane are assumed small, the vertical components of the forces on the edges *ad* and *bc* are, respectively,

$$V_1 = -Fdy \sin\theta_1 = -Fdy\frac{\partial z}{\partial x}$$

and

$$V_2 = Fdy \sin\theta_2 = Fdy\left[\left(\frac{\partial z}{\partial x} + \frac{\partial}{\partial x}\left(\frac{\partial z}{\partial x}dx\right)\right)\right] \quad \ldots\ldots (q)$$

The resultant of these vertical components is

$$V_x = V_1 + V_2 = Fdxdy\frac{\partial^2 z}{\partial x^2}$$

In the same way the resultant vertical component on the faces *ab* and *cd* of the element *abcd* is

$$V_y = Fdxdy\frac{\partial^2 z}{\partial y^2}$$

For equilibrium, the summation of the forces in the z direction for the element *abcd* must be zero or

$$qdxdy + V_x + V_y = 0$$

or

$$Fdxdy\left(\frac{\partial^2 z}{\partial x^2} + \frac{\partial^2 z}{\partial y^2}\right) + qdxdv = 0$$

That is,

$$\frac{\partial^2 z}{\partial x^2} + \frac{\partial^2 z}{\partial y^2} = -\frac{q}{F} \quad \ldots\ldots (9)$$

This is the differential equation for the deflected membrane, the values of z being the vertical ordinates of the points on the membrane referred to the original plane xy of the membrane before loading. Equation 9, furthermore, is similar to Equation 5 for the stress function ϕ. That is, from the deflections z of the membrane values of the stress function ϕ can be obtained by replacing the quantity $-q/F$ of Equation 9 with the quantity $-2G$ of Equation 5.

Further information on the torsion problem can be obtained from the membrane by considering the membrane represented by contours (lines with equal deflections z),

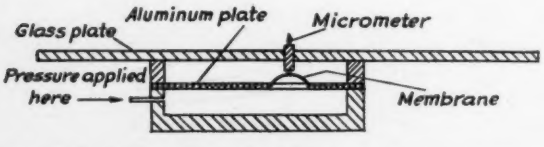


Fig. 11—Diagrammatic cross section of apparatus shown in Fig. 1

as shown in *Fig.* 10. Considering any point A on one of the contours as shown in this figure, the following relation holds for all points on this contour, since the deflection z is constant,

$$\frac{\partial z}{\partial s} = 0 \quad \ldots\ldots (10a)$$

The corresponding equation for the stress function is

$$\frac{\partial \phi}{\partial s} = 0 \quad \ldots\ldots (10b)$$

This latter equation can be written

$$\frac{\partial \phi}{\partial s} = \frac{\partial \phi}{\partial y}\frac{dy}{ds} + \frac{\partial \phi}{\partial x}\frac{dx}{ds} = S_{zz}\frac{dy}{ds} - S_{yz}\frac{dx}{ds} = 0$$

That is, the stress in the normal direction N is zero and the resultant stress is therefore tangent to the contour line. The magnitude of the shearing stress is obtained

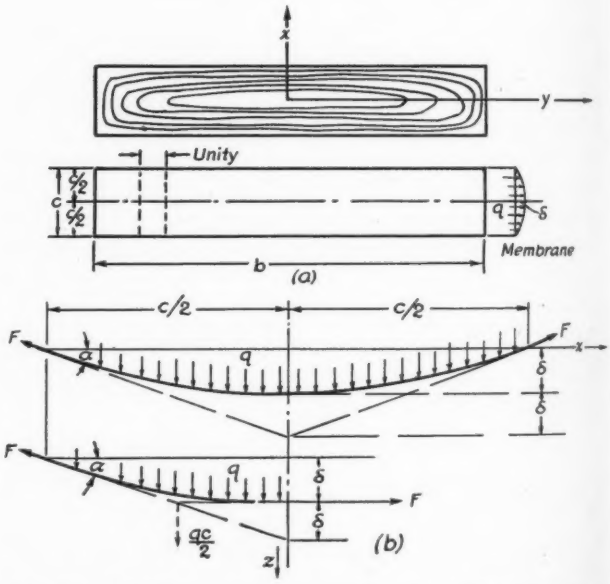


Fig. 12—Membrane analogy applied to narrow rectangular cross section

by projecting the stress component values in the direction at right angles to N in *Fig.* 10. Then this shearing stress is

$$S_s = -S_{zz}\cos\gamma + S_{yz}\sin\gamma$$

or

$$S_s = -\frac{\partial \phi}{\partial y}\frac{dy}{dn} - \frac{\partial \phi}{\partial x}\frac{dx}{dn} = -\frac{d\phi}{dn} \quad \ldots\ldots (11)$$

This means that the magnitude of the shearing stress at point A is determined by the maximum slope of the membrane at this point since the slope of the membrane in the normal plane N to a contour gives the maximum slope. The maximum shear, therefore, occurs where the contour lines are closest to each other.

A consideration of Equation 4 shows that if ϕ is replaced by z the integral represents the volume bounded by the deflected membrane and the xy plane, and the twist-

ing moment is equivalent to double the volume bounded by the deflected membrane and the xy plane.

The analogy between the equations of the membrane and the torsion stress function can be summarized as follows:

1. The tangent to any contour line at any point of the membrane gives the direction of the shearing stress at the corresponding point on the cross section of the twisted bar (Equations 10)
2. The slope of the surface of the membrane at a point, in a direction at right angles to the tangent of the contour at that point, gives the magnitude of the shearing stress at the corresponding point in the twisted bar (Equation 11)
3. Twice the volume included between the surface of the deflected membrane and the plane of its outline is equal to the twisting moment of the prismatic bar (Equation 4).

In the membrane analogy method a section of circular shape and also a section of the shape to be investigated are cut in a thin aluminum plate, *Fig.* 11. This plate is

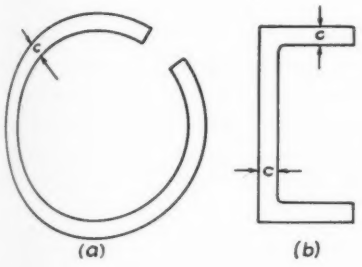


Fig. 13 — Members with thin-walled cross sections

clamped between two castings as shown. A soap film is stretched over the two openings, the ingredients of the solution being such as to produce as tough and as durable a film as possible. A rubber tube is attached through which air pressure can be applied with a small pump or with hydrostatic pressure produced by raising a tube filled with water. The contour lines of the inflated membranes are recorded by obtaining the elevations of different points on the membranes with the aid of a micrometer which is attached to a glass plate. This plate can be moved freely in a horizontal plane so that the elevations of all points on the membranes are obtained.

Care is necessary in slowly turning the thread of the micrometer until the lower pointed end of the micrometer is just in contact with the film. A record of the elevations is made on a board in a manner similar to that used in surveying with a plane table. This is accomplished by means of a board that turns about a shaft. A piece of drawing paper is attached to the board and, by means of the pointed upper end of the micrometer, the location of a point on the cross section can be transferred to the drawing paper. Knowing the elevations and positions of a series of points on the film it is then possible to sketch the contours. From the contours obtained the volumes under the membranes can be determined.

Since both membranes are subjected to the same pressure the values of q/F and hence $G\,\theta$ are the same. That is, the results obtained are for the section under consideration which has the same angle of twist as the circular section. This assumes equal values for the modulus G. Then if V = the volume in the case of the irregular section under consideration, and V' = the volume in the case of the circular section, the ratio of the twisting moment M_t to M_t' is

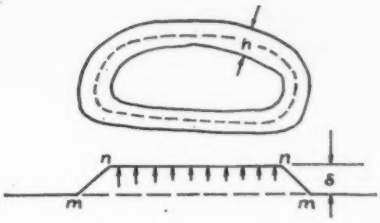


Fig. 14 — Member with closed thin-walled cross section

$$\frac{M_t}{M_t'}=\frac{V}{V'} \quad \text{or} \quad M_t=M_t'\left(\frac{V}{V'}\right) \qquad (r)$$

That is, considering a twisting moment M_t' on the circular section, the twisting moment on the irregular section is given by $M_t(V/V')$. Now, if the slope of film for the circular section at the edge is equal to α' and that for a point on the membrane of the other is equal to α, then for equal angles of twist the ratio of the shearing stresses for the sections is

$$\frac{S_s'}{S_s}=\frac{\alpha'}{\alpha} \qquad (s)$$

where S_s = the shear stress for the section under consideration and S_s' = the shear stress for the circular section.

For the case of the circular cross section,

$$S_s'=M_t'\left(\frac{r}{J}\right) \qquad (t)$$

Placing the value of S_s' from Equation t in Equation s the shearing stress on the section being investigated is

$$S_s=\left(\frac{\alpha}{\alpha'}\right)\left(\frac{M_t'r}{J}\right) \qquad (u)$$

Substituting the value of M_t' from Equation r in Equation u, the shearing stress produced by a twisting moment M_t is

$$S_s=\left(\frac{\alpha}{\alpha'}\right)\left(\frac{V'}{V}\right)(M_t)\left(\frac{r}{j}\right) \qquad (12)$$

The angle of twist per unit length for the circular cross section is

$$\theta=M_t'\left(\frac{1}{GJ}\right) \qquad (v)$$

Angle of twist per unit length in the section, due to a moment M_t, is obtained by placing the value of M_t' from Equation r in Equation v,

$$\theta=M_t\left(\frac{V'}{V}\right)\left(\frac{1}{GJ}\right) \qquad (13)$$

In this way the stresses and angle of twist in a prismatic bar of noncircular cross section can be obtained experimentally. The above equations for the stress and

(*Continued on Page* 198)

Improving Fatigue Streng

By J. O. Almen
Research Laboratories Division
General Motors Corp.

WHILE great strides have been made in most phases of engineering and metallurgy, it is doubtful whether in dynamically loaded parts more net work is being obtained from metals today than a generation ago. The fact that modern machines are generally lighter, cheaper and more compact than the equivalent machines of a generation ago is primarily due to higher operating speeds, better understanding of commercial requirements and reduced "factors of safety". New fabrication techniques have made possible many design improvements, better bearing materials are available, lubricants have been improved, but the basic useful strength of structural materials remains unaltered.

Although no super strength alloys have been discovered and no such discoveries seem imminent, much can be done to increase materially the fatigue strength of many machine parts made from ordinary materials. This fatigue strengthening does not require changes in design or in material, and in fact does not require processes that are fundamentally new or untried. It is merely the extension of processes that have long and honorable histories and the avoidance of processes and practices that are now known to reduce fatigue strength. The significance of these processes has only recently become clear through the introduction of concepts of fatigue phenomena by which new avenues of reasoning are opened to us. These new concepts are:

1. Fatigue failures result only from tension stresses, never from compressive stresses and

2. Any surface, no matter how smoothly finished, is a stress raiser.

Fully ninety per cent of all fatigue failures occurring in service or during test are traceable to design and production defects and only the remaining ten per cent are primarily the responsibility of the metallurgist as defects in material, material specification, or heat treatment. While this ratio is not a measure of the quality of workmanship contributed by each department, there can be no doubt that the metallurgist has a better appreciation of his responsibility for fatigue failures than has the designer, the engineer, or the man in the production department.

A familiar routine is followed when a failed part is received by the laboratory. The fracture is examined and is found to be due to fatigue, the material is analyzed for composition, sections are studied for all the many things that are metallurgically important and a report is written describing the things that are and are not up to par. But no matter how many possible metallurgical causes of trouble are found, such examination is far from sufficient unless the failure is also examined for design faults and possibly bad fabrication and assembly practice. Most engineers pass all fatigue problems on to the metallurgical department with the implication that something must be wrong with the material or with the heat treatment. The metallurgist does his metallurgical best and in the process, frequently destroys the evidence of mechanical faults. The study of fatigue of materials is properly the joint duty of the metallurgical, engineering and production departments.

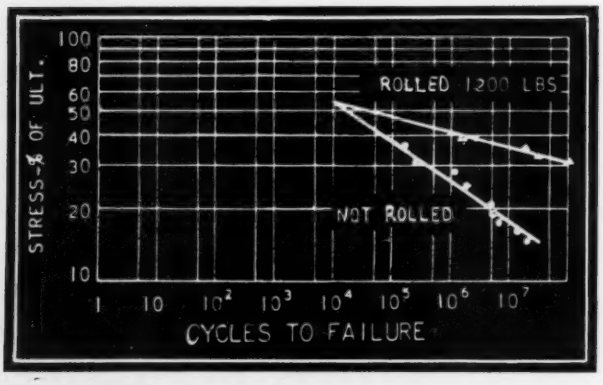


Fig. 1—Rolling of railway axles prestresses the surface material, increasing fatigue resistance

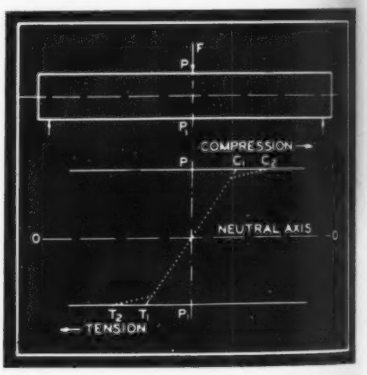


Fig. 2 — Theoretical stress at any point in plane PP¹ of loaded beam is measured by distance to line C_1T_1. Added stress due to surface effect is denoted by T_1T_2

Surfaces of repeatedly stressed specimens, no matter how perfectly finished, are more vulnerable to fatigue than the deeper layers. It has long been appreciated that vulnerability to fatigue increases as the surface roughness is increased, particularly if the roughness consists of sharp notches and especially if the notches are oriented at right angles to the principal stress. The practice of carefully finishing fatigue test specimens and engine parts is, of course, a recognition of this vulnerability in so far as visible marks or scratches are concerned, even down to assuring that the final polishing marks are parallel to the direction of the applied stress. These precautions are known to be effective in increasing the fatigue strength of the specimens and specimens finished in this manner have,

Machine Parts

therefore, come to be known as "par" bars. This name implies that fatigue specimens and machine parts approaching perfection in finish give the highest possible fatigue endurance for any particular material and that they accurately measure the ultimate fatigue properties of that material.

It can be shown, however, that the so-called par bars are not the best specimens and that influences akin to notches, so far as fatigue vulnerability is concerned, are retained by the par specimens. It seems that the specimen surface is highly vulnerable simply because it is a surface, there being an extra hazard in the surface layer not shared by the deeper layers. This may be due to submicroscopic notch effects or to the fact that the surface is a discontinuity since the outer crystals are not supported on their outer faces.

Fatigue strength of the most carefully prepared speci-

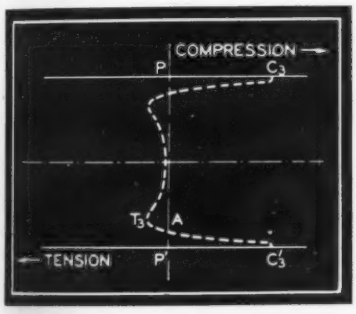


Fig. 3—Stress distribution in an unloaded beam with surfaces prestressed in compression is probably something like this

men will be increased if a thin layer of the specimen is prestressed in compression (1)* by a peening operation such as peen hammering, swaging, shot blasting or tumbling or by pressure operations by balls or rollers. The increase in fatigue strength resulting from the surface layer being stressed in compression is clearly shown by the *S-N* curves, *Fig.* 1, which compare normally finished railway axles with axles that had been subjected to a rolling operation (2). This and many other tests show that the compressively stressed surface is effective in increasing the fatigue strength whether applied to highly finished specimens or to specimens having rough surfaces.

A familiar example is the improvement in fatigue that may be obtained by a few cycles or overload sufficient to produce a "set" in such parts as springs. Local tension stresses from the overloads exceed the elastic limit of the material, therefore the tension stress at the working load is decreased. This treatment which has long been practiced on many production items, is similar in effect to rolling or peening since, in the unloaded state, the member is stressed in compression in the areas where yield occurred during the overloading.

Durability comparisons cannot be made on percentage basis alone as is apparent from *Fig.* 1. If the durability

*References in parentheses are listed at end of article.

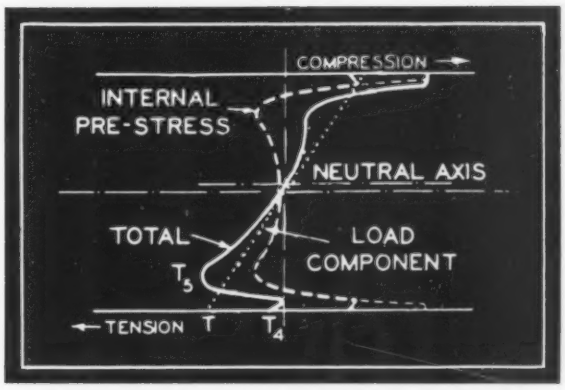


Fig. 4—When bending load is applied to prestressed beam the stress distribution is as indicated by solid line. Note shift of neutral axis

comparison is made at a load equal to fifty-five per cent of the ultimate strength, the percentage improvement is zero, if made at a load corresponding to twenty per cent of the ultimate strength, the percentage improvement is infinite and, at intermediate loads, the percentage gain will be somewhere between these limits.

The most plausible explanation of the effectiveness of surface compression stress (3) is that when a load is applied to such specimens the tension stress in the surface layer is less by the amount of the compression prestress and, since fatigue failure starts from tension stress, the fatigue durability of the weak surface layer is increased. However, the tension stress in the material below the prestressed layer is not reduced but may be actually increased, notwithstanding which the fatigue strength of the specimen is increased. It follows, therefore, that the lower layer is inherently stronger than the surface layer.

Foppl (4) shows that the fracture in rolled specimens does not originate at the surface but in the material below the prestressed layer as would be expected if the surface is sufficiently prestressed in compression. Similar subsurface fatigue failures, usually called fissures and attributed to faulty material, have long been known to occur in railroad rail in which the surface is stressed in compression as a result of the cold work of heavily loaded locomotive and car wheels.

The situation can be clarified by use of the conventional textbook stress diagram of a loaded beam, as illustrated in *Fig.* 2, in which a beam supported at the ends is loaded in the central plane, PP_1. The stress at any point in the beam is measured by the horizontal distance from the plane in which the load is applied to the diagonal line

***SURFACE** weakness is the chief obstacle to obtaining more effective fatigue resistance from present-day materials. In this article, which is based on a paper presented at the twenty-seventh annual meeting of the A.G.M.A., the author discusses surface effect and how it can be offset by prestressing. The information given should enable designers to provide increased life for fatigue-loaded parts*

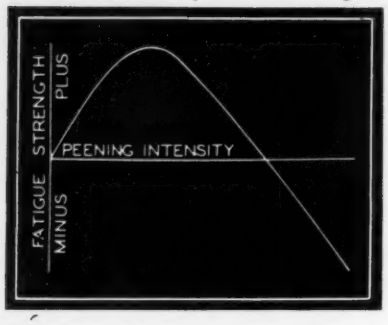


Fig. 5—Peening or rolling, depending on intensity, can have beneficial or adverse effect on fatigue life

T_1C_1. The distance PC_1 represents the compressive stress at the upper surface, the stress at the neutral axis OO is zero and the tension at the lower surface is represented by the distance T_1P_1.

While this is a satisfactory enough stress diagram for static loads, it does not agree with the behavior of fatigue specimens. However, modifying the diagram so that T_1T_2 represents an added increment of tension stress in the surface gives a reasonable representation of the surface fatigue vulnerability. As the surface roughness is decreased the increment T_1T_2 decreases, but no matter how well polished the specimen, there remains an additional surface stress.

Residual stress pattern in an unloaded beam that has been rolled or peened is pictured in *Fig.* 3, where C_3P and $C_3'P'$ represent the magnitude of compressive prestresses and T_3A represents the magnitude of the tension prestress to balance the compressed stresses in the surface. After this beam has been loaded from either side through one stress cycle, as in a reversed fatigue test, the compression prestress will be reduced if the applied load raises the total compression stress above the yield point. The stress diagram for such a prestressed beam supporting an external load is shown in *Fig.* 4, where the effective tension stress T_4 at the surface may be less than the stress T_5 below the surface, in which case failure would start below the surface. The neutral axis is displaced from the geometric center of the beam and the tension stress T_5 below the surface is greater than in the beam that had not been prestressed.

Further evidence of the extra vulnerability of the surface layer is found in the behavior of specimens having increased strength in a surface layer as in thinly carburized or cyanided specimens or in thinly nitrided specimens. Fatigue failures in such specimens also start below the surface and show greater fatigue strength than the same material in the unclad state. A nitrided specimen is probably superior to the other forms of hard cladding because, in addition to possessing higher physical properties, the surface layer is in a state of compression and is therefore less notch sensitive.

Prestressing by Heat Treatment

Mention should be made of surface compressive stress obtainable by heat treatment. By a rapid quench it is possible, through thermal contraction alone, to trap compressive stress in the surface and corresponding tension stress in the core. Perhaps the most spectacular use of surface compression stress by heat treatment through thermal contraction alone is tempered glass which, because of its great strength, is used in parts of modern automobiles. This glass is prepared from normal glass by rapidly cooling the surfaces by air jets. The cooled surfaces contract causing the relatively plastic center to yield in compression. As the center of the glass cools and contracts it becomes stressed in tension with consequent compressive stress in the surfaces.

With the known sensitivity of materials to fatigue, it is obvious that control of cold work is just as important as control of heat treatment in order to benefit by the good effects and overcome the evil effects. Cold working can be good or bad, depending upon how it is done and for what purpose. Papers have been published showing that cold working of the surface to produce a layer stressed in compression increases the fatigue strength of the parts to which it is applied, but the amount of prestress or the depth of the prestressed layer is not disclosed. Both values presumably are important in obtaining optimum results but it is probable that the value should not be the same for all sizes of specimens, for all materials, or for hard and for soft specimens.

Several instances are known in which the strength of machine parts and specimens have been decreased by too intense surface peening. *Fig.* 5 shows the probable effect

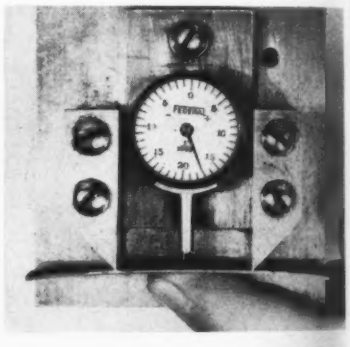


Fig. 6 — Curvature indicator measures effect of peening or rolling thin strip, enables depth of stressed layer to be calculated

of peening or rolling on thin sections. Fatigue strength is increased as the intensity of peening or rolling is increased until a maximum improvement is obtained. With more intense peening or rolling, the fatigue strength rapidly decreases below the original strength and the part will be damaged due to excessive internal tension stresses.

When the layer is stressed in compression to a degree exceeding the yield strength of the metal in compression, the amount of residual stress is presumably at least equal to this yield strength. The depth of the stressed layer is probably roughly proportional to the instantaneous area over which the pressure is applied, and to the pressure intensity. Depth of the compression-stressed layer in a railroad rail (5) should be greater than the depth of the compression-stressed layer in the same material if small rollers at the same pressure intensity were used instead of large car wheels. Under these circumstances, the initial point of fracture should appear at corresponding depths. Such evidence as is available indicates this to be true.

A simple and practical method for indicating the compression in the stressed layer consists of a thin flat strip, attached to a heavy base, which is rolled or peened with the same intensity that is given to the machine part. When removed from the base it will be found to be curved with the convex surface on the cold-worked side. Curvature

of the strip may be measured by an indicator, as shown in *Fig.* 6, and can be interpreted in terms of the depth of the stressed layer.

Stress magnitude and depth of the stressed layer at constant cold work intensity of two such test strips are shown in *Fig.* 7. The cold-worked surfaces of these strips, the rockwell *C* hardnesses of which were, respectively, 64 and 40, were honed away in small increments and the curvature measured with the removal of each thin layer. The changing curvature as metal was removed provided data from which the compressive stress in each layer could be calculated. As would be expected, because of the higher yield point, the harder specimen was found to be more highly stressed than the softer specimen.

Also shown in this chart is the surface compressive stress in a specimen as a result of nitriding. The procedure for this experiment was the same as for measuring the stress due to peening except that the face of the specimen that was in contact with the heavy base was plated to limit the nitriding to the outer face of the strip. On removal from the base after nitriding the strip was curved convex on the nitrided side. It seems, therefore, that the well known resistance of nitrided specimens to fatigue is primarily due to the compressively stressed surface layer.

Although the usual experience with nitriding is that it greatly improves fatigue strength, it is possible to overdo nitriding just as it is possible to overdo surface stressing

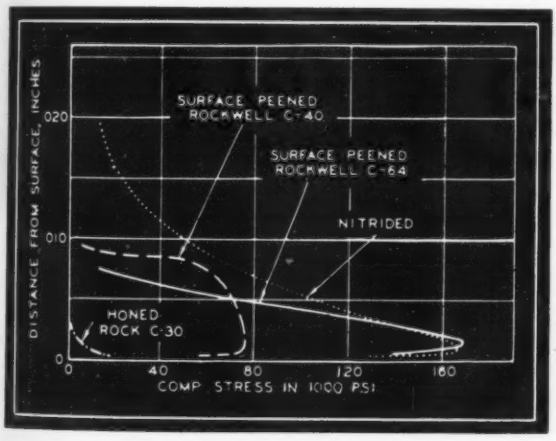


Fig. 7—Stress at various depths below surfaces due to different surface treatments

by peening and rolling. The high compressive surface stress that results from nitriding must, of course, be balanced by internal tension stress of equal total value. When deep nitriding is applied to light sections the unit internal tension stress may reach dangerous proportions.

The part shown in *Fig.* 8 was greatly reduced in strength as a result of nitriding, its fatigue durability being only one or two per cent as great as the fatigue durability of the same part not nitrided. The diameter of the part at the point of failure was approximately one-eighth inch. Depth of the nitrided layer was about .02-inch, the area of which is equal to sixty per cent of the area of the section as is shown by the circle in the enlarged view. From the compressive stress diagram shown in *Fig.* 7, it is evident that the internal tension stress must have been very great.

It is also known that internally nitrided cylinder barrels are more prone to fail by cracking than cylinder barrels that are not nitrided, the reason being that the stress due to nitriding is added to the stress from gas pressure. Care must therefore be used in nitriding thin sections to gage the depth of the nitrided layer in proportion to thickness of the section being nitrided.

While the peened specimens used for the experiment shown in *Fig.* 7 were being honed as has been described, it was found that the strips did not fully recover their original flat form. To determine if this residual curvature was due to a "set" in the material or was the result of honing, other flat strips that had not been peened were honed. These strips developed the same curvature as the residual curvature in the peened specimens, demonstrating that honing produces a compressively stressed layer. The approximate magnitude of this honing stress is also shown in the chart, *Fig.* 7. This raises a question as to the state of surface stress in the carefully prepared fatigue specimens favored for laboratory fatigue tests since additional tests have shown that lapping also introduces surface compressive stress.

Prestressing by Carburization

The carburized layer in a carburized part is stressed in compression as is graphically shown in *Fig.* 9. Two opposite faces of this half-inch square specimen were carburized while the other two faces were protected by copper plating. The specimen was quenched and tempered in the usual manner after which it was split with a saw as shown in the lower view. The fact that the parts are curved convex on the outer faces indicates compressive stress in these faces. Analysis of the internal stresses in another carburized member by a method similar to that described for peened and nitrided strips indicated the internal stress pattern shown in *Fig.* 10. Of interest is the magnitude of the compressive stress in the carburized layer and the reduced compressive stress, possibly even tension stress, in a thin surface layer. When carburized parts such as bearing races, wrist pins and gear teeth are ground the surface may be stressed in tension as is indicated by the dotted lines shown at the right of the diagram in *Fig.* 10.

The compressive stress in the carburized layer is a hazard for members stressed in tension as was shown for the nitrided part, *Fig.* 8, because the tension stress in the core is equal to the working load plus the tension load due to

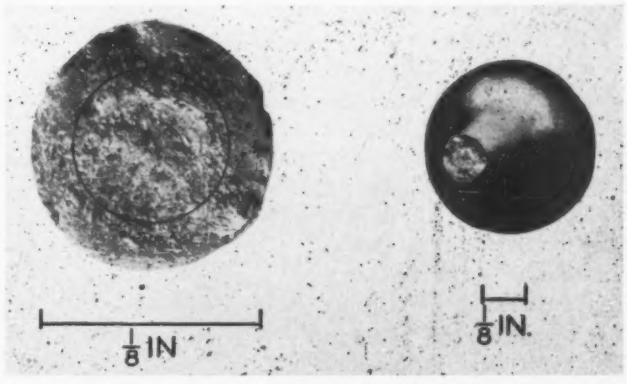


Fig. 8—Fatigue failure of this part resulted from severe tension stress due to deep nitriding

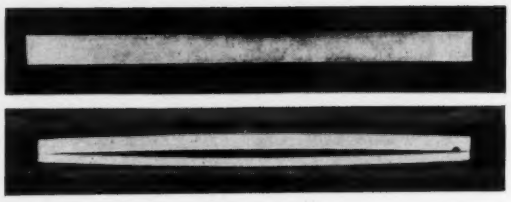


Fig. 9—Upper view shows piece before splitting, lower shows effect of compressive stresses in the carburized and hardened upper and lower surfaces when piece is split

the compressive preload of the case. For members stressed in bending and in torsion, however, the compressive stress in the carburized case of ordinary depth improves the fatigue strength of the part except for the thin surface layer which, especially after grinding, is severely stressed in tension. It is however, a simple matter to convert this thin tension-stressed layer into stress in compression by suitable peening or rolling operations as was indicated in *Fig.* 7 with resultant large gains in bending and torsion fatigue strength.

Shows Origin of Warpage in Carburized Parts

With internal stresses of the magnitude shown in *Fig.* 10 it is easy to understand why carburized parts are prone to warp during heat treatment, especially if the design is not symmetrical with respect to the internal stresses.

Residual stresses due to quenching from relatively low temperatures may reach considerable magnitudes and may be harmful or helpful to fatigue durability depending upon whether the trapped stresses augment or diminish the tension stresses from the applied loads. An interesting case of this kind occurred in a water cooled aluminum cylinder head, *Fig.* 11, that failed by fatigue on the water side of the combustion chamber wall. Measurements of residual stress disclosed that the water side of the wall was stressed in tension and the combustion chamber side in compression. This internal stress pattern was of the same kind as the stress from the gas pressure against the combustion chamber wall and the resultant stress was therefore the sum total of the residual stress and the gas pressure stress.

Residual stresses in this case were caused by quenching the cylinder heads from 980 degrees Fahr. by immersion in cold water. The outer surfaces of the casting were cooled while the inner water jacket surfaces, especially at the thick section, were still hot. Thermal contraction of the outer surfaces imposed compressive stresses of such magnitude as to cause yield in the still hot and therefore weaker water jacket surface. As cooling progressed, the metal that had been stressed beyond the yield point contracted thermally leaving tension stress on the water jacket side and corresponding compression stress on the combustion chamber side. Retention of the residual stress in the thick combustion chamber wall was aided by the thinner outer wall of the water jacket which was stressed in compression.

As a correction of the undesirable residual stress, another cylinder head was given the same heat treatment except that it was quenched internally by forcing cold water through the water jacket. When internally quenched, the stress pattern in the combustion chamber wall was reversed, leaving the inner side in compression and the outer side in tension. Since these trapped stresses were of opposite sign to the operating stress the resultant stress was the difference between the residual and operating stresses instead of their sum as when the casting was quenched externally. Fatigue tests were conducted on cylinder heads quenched by both methods, the results of which were 2,000,000 to 3,000,000 stress cycles to failure for the externally quenched heads and 5,000,000 to 6,000,000 stress cycles for the internally quenched heads. Additional fatigue tests were made on internally quenched heads in which the aging treatment at 350 degrees Fahr. was omitted in order to avoid reduction of the favorable stress pattern. These heads endured more than 14,000,000 stress cycles at the same test load without failure.

Similar residual stresses are known to occur in many other heat-treated and quenched aluminum parts. It is also known that many aluminum parts show better fatigue

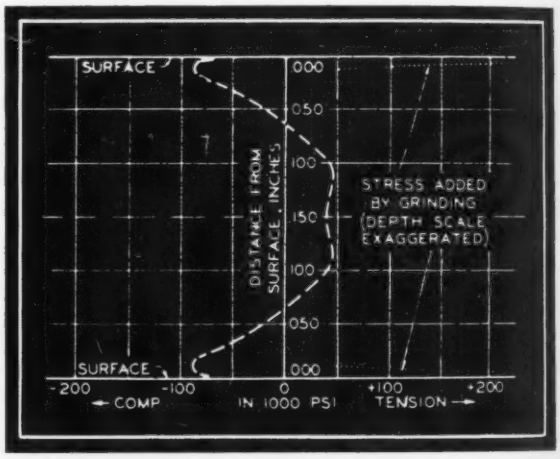


Fig. 10—Residual stress distribution across section of a bar, due to carburizing and hardening. Additional stresses result from grinding

resistance when they are drawn to a higher temperature than that which gives the greatest tensile strength presumably because unfavorable residual stresses resulting from quenching are thereby reduced. It is probable that similar stresses can be trapped in steel by quenching from tempering temperatures (6). Such residual stresses may be favorable or unfavorable depending on the shape of the part, the temperature gradient, and the direction of heat flow.

Fatigue failures in many machine parts are traceable to corrosion of several kinds or to other forms of surface damage that occur in service. In normal machine parts even slight corrosion or bruising is very potent in encouraging fatigue fractures because each pit interrupts the continuity of the surface and increases the local stress. The damaging effect of corrosion or bruising is prevented on surfaces that are adequately protected by compressive prestress because the local tension stress cannot reach dangerous values until the pits or bruises have progressed sufficiently to penetrate the compressively stressed layer. This was forcefully demonstrated in fatigue tests of a machine part that failed alternately in a badly formed fillet or in the region of a clamp remote from the fillet where fretting corrosion occurred. The durability of the

part could not be increased by improving the fillet because this would merely transfer all failures to the fretted area at about the same durability. After peening, however, the fatigue durability was found to have increased several hundred per cent and large additional gains were then possible by improving the form of the fillet without failure in the corroded area. The peening did not prevent corrosion but it did prevent the ill effect of corrosion in promoting fatigue.

Similar protection against the effects of corrosion and of surface bruises is afforded by nitriding,(7), carburizing and other treatments that produce compressively stressed surfaces. The working face of a gear tooth may be severely pitted, creating a fatigue hazard, but the bending fatigue strength may not be impaired because the carburized layer is compressively stressed and the surface is compressively stressed by the cold work of the mating teeth.

Efforts to improve products by improving surface finish may sometimes have the opposite effect. Highly finished surfaces and fillets may lead to a false sense of security if, as the result of machining or straightening operations, the parts have high internal stresses of the wrong kind. When machine polishing is done by the use of abrasive paper or cloth wheels, or abrasive-covered felt wheels, sufficient heat is often generated to induce serious surface tension stresses and thus promote instead of prevent fatigue failures. In ground surfaces such as shafts, wristpins, and gear teeth, the grinding operations may introduce high surface tension stresses that from the standpoint of fatigue strength, often do more harm than good. The surface tension stresses from grinding are often so great as to produce surface cracks.

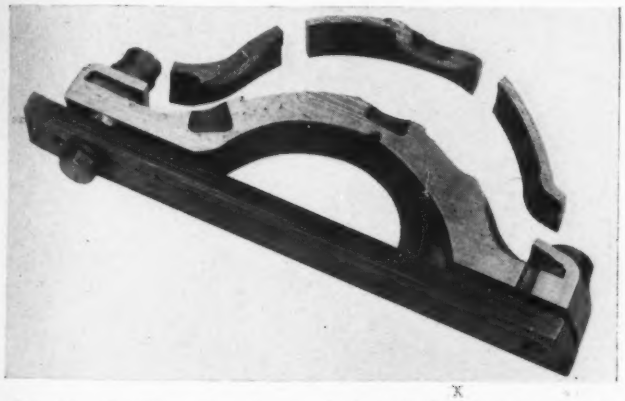
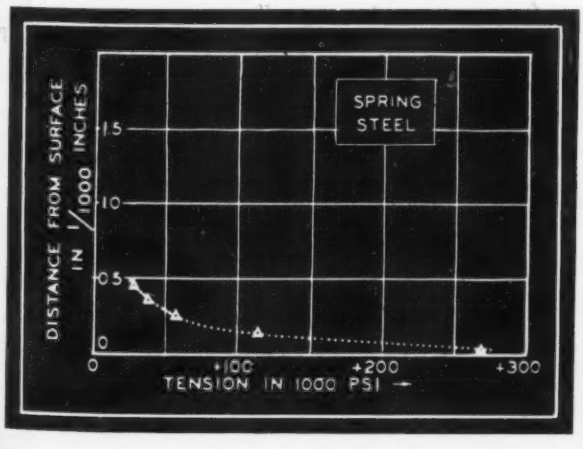


Fig. 11—Section of water-cooled cylinder head in which residual stresses were set up due to quenching

Fig. 12—Below—Residual stress caused by grinding reaches high values at surface layer



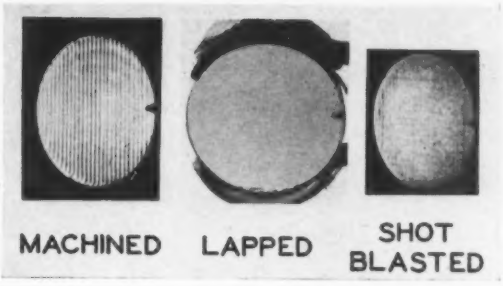


Fig. 13—Piece was rough machined (left), carburized, heat treated, ground and lapped (center), then shot blasted (right). Material failed to recover from machining damage even after prolonged heating at high temperature

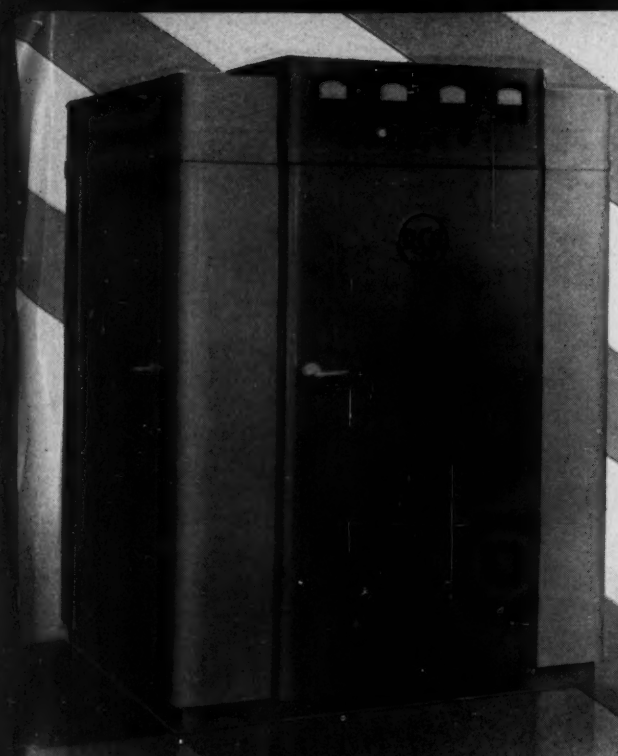
The magnitude of surface tension stress in a specimen that was ground in accordance with normal commercial practice is shown in *Fig.* 12. A specimen of annealed spring stock of one-sixteenth inch in thickness, one inch wide, and seven inches long was ground to a depth of .002-inch. After grinding, the previously straight specimen was found to be curved concave on the ground side indicating tension stress. Thin layers were then removed from the ground surface by hand honing until the specimen regained its initial straightness. Measurements of the change in curvature with each thin layer removed permitted calculation of the stress distribution shown in the chart. Surface stresses of this magnitude are not unusual in ground production parts but their presence is seldom realized unless actual failure has occurred.

Grinding Heat Cycle Hardens Surface Layer

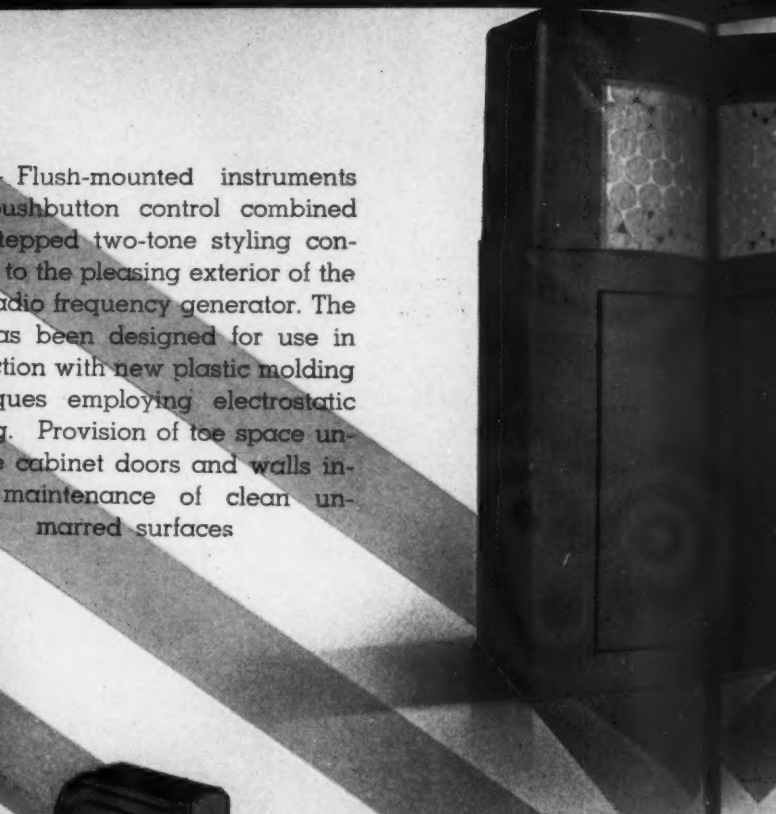
Obviously a stress of 270,000 pounds per square inch—just below fracture point of full hard steel—could not be supported by the steel in the annealed state, from which it follows that the stress layer was hardened by the heat cycle of the grinding operation to not less than rockwell C 55. The extreme thinness of the hardened layer presents an interesting problem in hardness measurement. Hardness numbers were practically identical for both ground and unground pieces, demonstrating the futility of normal technique for measuring the hardness of the most significant portion of machine parts—the surface layer.

In turning, milling and other machine operations, it is necessary that metal be removed at a minimum cost, therefore the cutting tools must often take deep cuts at high feed rates. Since metal cutting is more accurately described as a metal tearing operation so far as stresses are concerned, it is not surprising to find serious internal stresses to considerable depths after machining. When metal cutting has been unusually severe or after operations such as punching and shearing, often the surfaces are actually fractured. Finish machining or grinding rarely goes deep enough to remove the internally stressed metal from previous rough machining and, of course, these finishing operations add stresses of their own. Whenever it is economically practicable, internal stresses that produce tension in

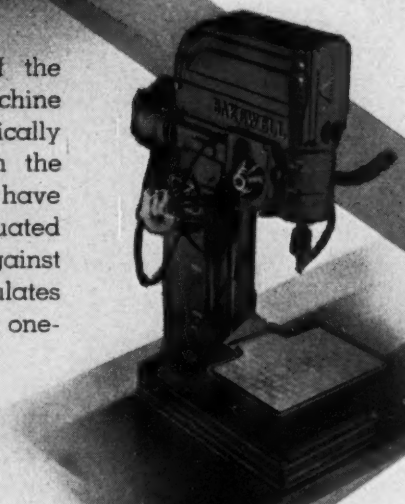
(*Continued on Page* 192)



Left — Flush-mounted instruments and pushbutton control combined with stepped two-tone styling contribute to the pleasing exterior of the RCA radio frequency generator. The unit has been designed for use in connection with new plastic molding techniques employing electrostatic heating. Provision of toe space under the cabinet doors and walls insures maintenance of clean unmarred surfaces



Right — Leading-on mechanism of the Bakewell bench model tapping machine consists of a lead screw and electrically operated guide fingers into which the precision threads of the lead screw have been hobbed. Sensitive solenoid-actuated clutch guards the small taps against breakage and a limit switch regulates depth of the tapping stroke to within one-tenth of a cycle



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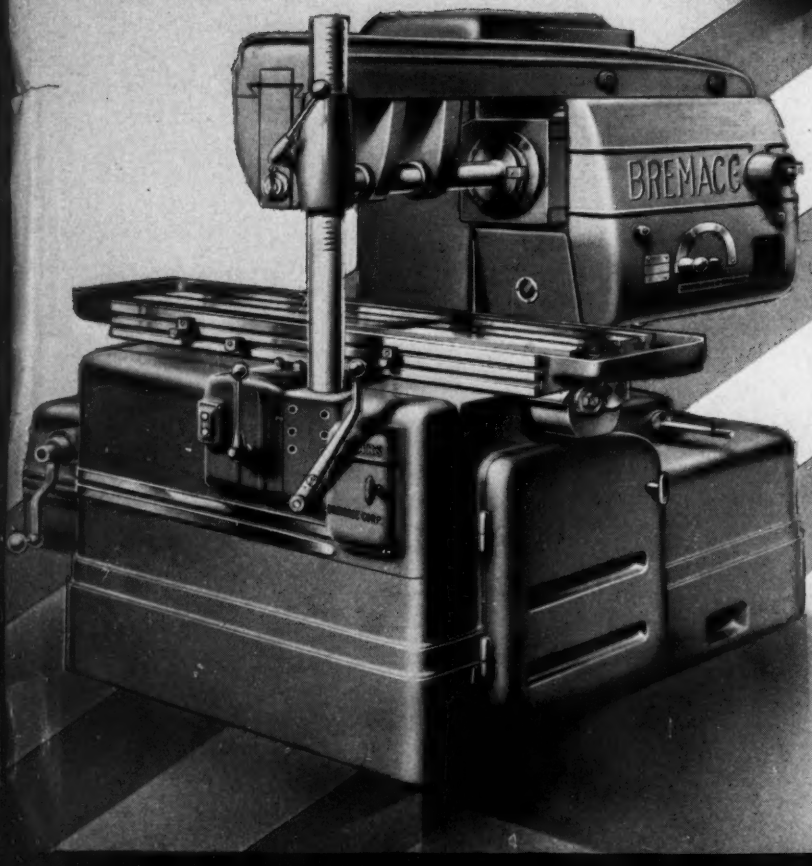


Left — Axial play in thread shoulders of the lead screws on the Bremacc down-cut milling machine is avoided through the use of twin lead screws so connected that the effective bearing surface with the feed nut is constantly under pressure. Plungers with hardened rollers, operated by table dogs, provide automatic cycling if desired. Power is supplied from an adjustably mounted motor

Below — Now b sed b plants for engr identif marks on tools a duction the Burgess W ol e needles vibratin 0 strok second. Molde ic cas tributes to light he co unit weighing ne po

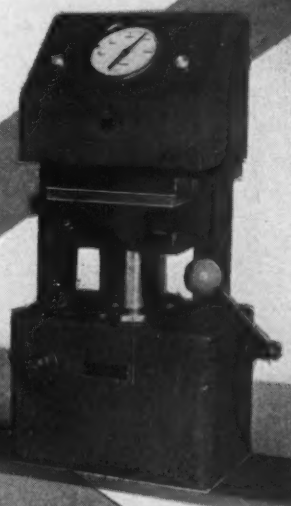
Left—Motor-driven fan in the Bargar portable dust collector receives dust-laden air from grinder or other machine and returns clean air to the shop. Heavy particles are precipitated in a cyclone separator while lighter dust is trapped in a replaceable spun-glass filter. Cabinet is of all-welded construction with black wrinkle finish

Above — In demand for su... and other small craft, the Electron... kilowatt range is designed for use where generating capacity is limited. Double-shell insulated oven, thermostatically controlled, is finished in bronze aluminum. Polished oil-treated steel replaces stainless steel in the construction of the range

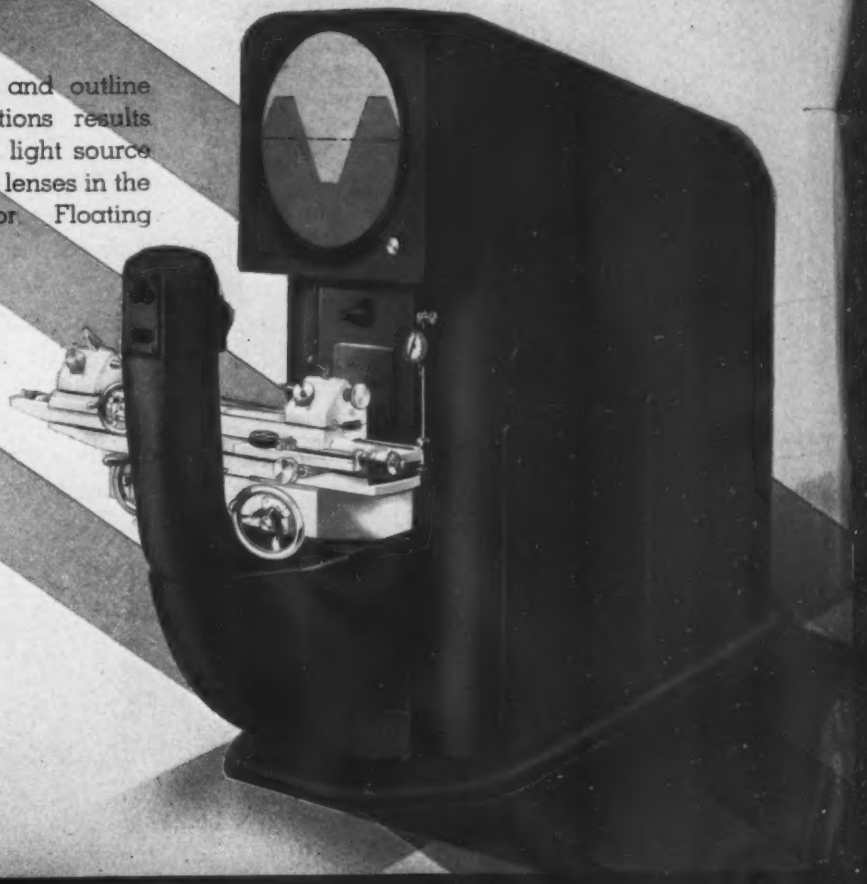
Machines and Guns

(For new machine, see page 210)

Left — Two-stage dual-stroke hydraulic pump on the Preco laminating and laboratory press provides for rapid closure of the platens followed by quick development of maximum pressure. Platens are electrically heated with thermostatic control and are self-aligning, insuring even pressure over the entire surface of the work



Right — Uniformity of light and outline definition at all magnifications results from the use of tungsten-arc light source and matched-type condenser lenses in the Portman optical comparator. Floating roller mounting design permits rapid and precise control of protractor image screen. Standard lens units provide magnifications from 10X to 100X



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MACHINE Editorial DESIGN

Nation Looks to Designers To Prevent Misuse of Alloy Steels

DESPITE the emphasis placed on the necessity for reduction in the use of alloy steels, more and more of these alloys are being employed in the war program. Whereas about seven per cent of total peacetime steel requirements consisted of alloy steels, the figure now is nearer to twenty per cent of the steel being produced.

Though the steel industry is making heroic efforts to increase its production of alloys and thus assist in keeping United States war equipment ahead of the field, there are specific limits to the amount that can be turned out in relation to the total steel production. Insufficient supplies of alloying elements on the critical list such as molybdenum, nickel and chromium are also seriously retarding the steel companies' efforts.

Experience in the application of the lower alloy National Emergency steels has not yet been completely successful in this country as a conservation measure. In the use of similar types of low-alloy steels, Britain and Canada are ahead of us. The amount of such steels employed in relation to the total of alloy steels used in the United States is about 24 per cent, in Britain 35 per cent, and in Canada 50 per cent.

Though it is not practicable to reduce the alloy content of steel used in many types of ordnance, there evidently is a great deal yet to be done in effecting savings in other forms of war equipment and production machines. This challenge still confronts the designer. Regardless of whether it is possible for him on priority to obtain steels of high alloy content, his first consideration should be whether a lower alloy will do the job sufficiently well to permit its specification.

There is only so much to go around. In order to insure continuance of the trend toward victory it behooves us to put forward every effort to be sure that scarce material is used only in minimum amounts and where full justification exists.

L. E. Jerry

Properties of Thermoplastics

By T. S. Carswell and Turner Alfrey
Monsanto Chemical Co.

IN PRACTICE the term thermoplastic is understood to apply to organic materials which soften sufficiently to become moldable at temperatures not exceeding 500 degrees Fahr. As a class, thermoplastics possess the following general advantages:

1. They may be fabricated to finished form by a wide variety of methods, each of which permits considerable latitude. These processes include compression molding, injection molding, extrusion molding, blowing, swaging, drawing, casting (either from solution or from incompletely polymerized sirups), laminating, punching, shearing, and machining.
2. They are easily molded by fast, economical processes, to give a complete finished part, containing inserts if desired, and requiring no painting or other finishing since color and surface are integral.
3. Sprues, runners and rejected moldings may be salvaged by grinding and remolding, since the molding process is completely reversible.

In addition, many members of the group possess individual advantages, such as toughness, electrical characteristics, glass-like clarity, elasticity, etc.

On the other hand, thermoplastics in general suffer from the following disadvantages:

1. Since they soften when heated, they cannot be used in situations where high temperatures are encountered. Generally speaking, thermoplastic parts will not withstand stresses at temperatures above 212 degrees Fahr. and for most materials the maximum safe operating temperature is considerably lower. This is the most important obstacle to more widespread use in electronic apparatus.
2. In common with many other engineering materials, thermoplastics undergo creep or cold flow even at ordinary temperatures and at stresses far below short-time test strength values.

In addition to these communal disadvantages, members of the thermoplastic group may possess individual disadvantages such as high water absorption, poor weather and dimensional stability, loss of plasticizer on aging, brittleness at low temperatures, etc.

Thermoplastic materials for which proved applications exist are listed below, along with their principal uses, advantages and limitations. Physical and electrical characteristics of these materials are compared in the table, Pages 134 and 135.

Cellulose Derivatives

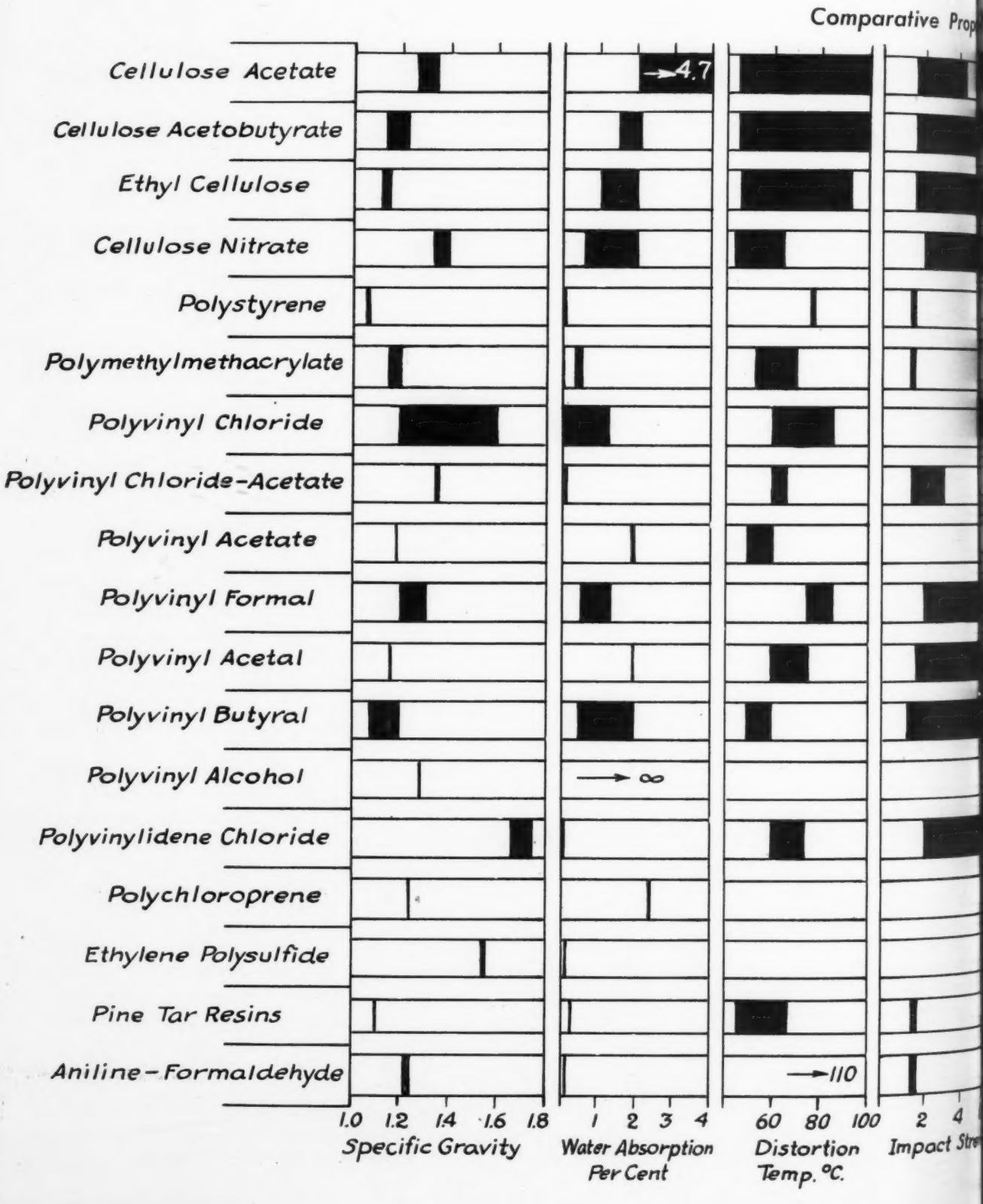
1. CELLULOSE ACETATE (Fibestos, Tenite I, Plastacele, Lumarith, Nixonite): Housing, knobs, controls, transparent coverings, winding tape, handsets. Excellent moldability and good toughness; characteristics may be varied over wide range by varying type and amount of plasticizer. Moderately high water absorption and volatility of plasticizers cause dimensional change on aging. Weather resistance only fair. Becomes brittle at low temperatures. Not useable above 212 degrees Fahr., and most types not above 140 if stressed.
2. CELLULOSE ACETOBUTYRATE (Tenite II): Generally similar to cellulose acetate but more water resistant and dimensionally stable; weathers better.
3. ETHYL CELLULOSE (Ethocel, Ethyl Rubber): Generally similar to cellulose acetate and acetobutyrate. Fairly good water resistance and dimensional stability, but weather resistance is only fair. Some varieties have fairly good toughness at low temperature. Used in extruded, flexible wire covering.
4. CELLULOSE NITRATE (Celluloid, Nitron, Pyralin, Nixonoid): Tough and dimensionally stable but highly inflammable and weathers poorly. Used in tool handles, drawing instruments, scales and dial faces, battery separators.

Vinyl-Type Polymers

1. POLYSTYRENE (Styron, Lustron, Loalin): Exceptionally good electrical characteristics, moisture resistance, clarity and dimensional stability. Low ductility, however, limits toughness; maximum operating temperature is about 160 degrees Fahr. or lower if subjected to appreciable stress. Widely used in radio apparatus, refrigerator parts, battery cases and lighting fixtures.
2. POLYMETHYLMETHACRYLATE (Plexiglas, Lucite): Generally similar to polystyrene in appearance and mechanical properties, but inferior electrically. Slightly better clarity and weather resistance. Used in dial and gage covers, housings, reflectors.
3. POLYVINYL CHLORIDE (Koroseal): Good electrical characteristics and practically nonflammable. May be varied from hard rigid solid to soft, flexible elastomer by selection of plasticizers. Thermal stability and clarity are only fair. Widely used for wire and cable coverings, wrapping foils.
4. POLYVINYL CHLORIDE-ACETATE (Vinylite): Generally similar to polyvinyl chloride but has better clarity, stability and moldability. Used for wire and cable covering, and for molded parts.
5. POLYVINYL ACETATE (Gelva): A soft resin with a relatively narrow temperature range between brittle and tacky points. Chief use is in adhesives.
6. POLYVINYL FORMAL (Formvar): Tough strong plastics with properties which may be varied by plasticization. Water resistance is only fairly good and maximum usable temperature about 115 to 160 degrees Fahr.
7. POLYVINYL ACETAL (Alvar): Properties generally similar to Polyvinyl Formal. Widely used as an ingredient of a superior wire-coating enamel

and has been used to some extent for molded parts.

8. Polyvinyl Butyral (Butvar): Properties generally similar to Polyvinyl Formal. Has been used chiefly for the interlayer in high-test safety glass but has found wartime uses as a replacement for rubber in waterproof clothing and fabrics.
9. Polyvinyl Alcohol: This material has excellent oil resistance but is sensitive to moisture. It has found few electrical applications.
10. Polyvinylidene Chloride (Saran): Resembles polyvinyl chloride in some respects, but may be produced in the form of oriented, crystalline filaments or moldings of high strength. Used in flexible tubing, moisture-proof wrapping foil, etc.
11. Polychloroprene (Neoprene): One of the best of the synthetic rubbers, this material has excellent resistance to petroleum hydrocarbons, to heat and oxidation, and is widely used where these proper-

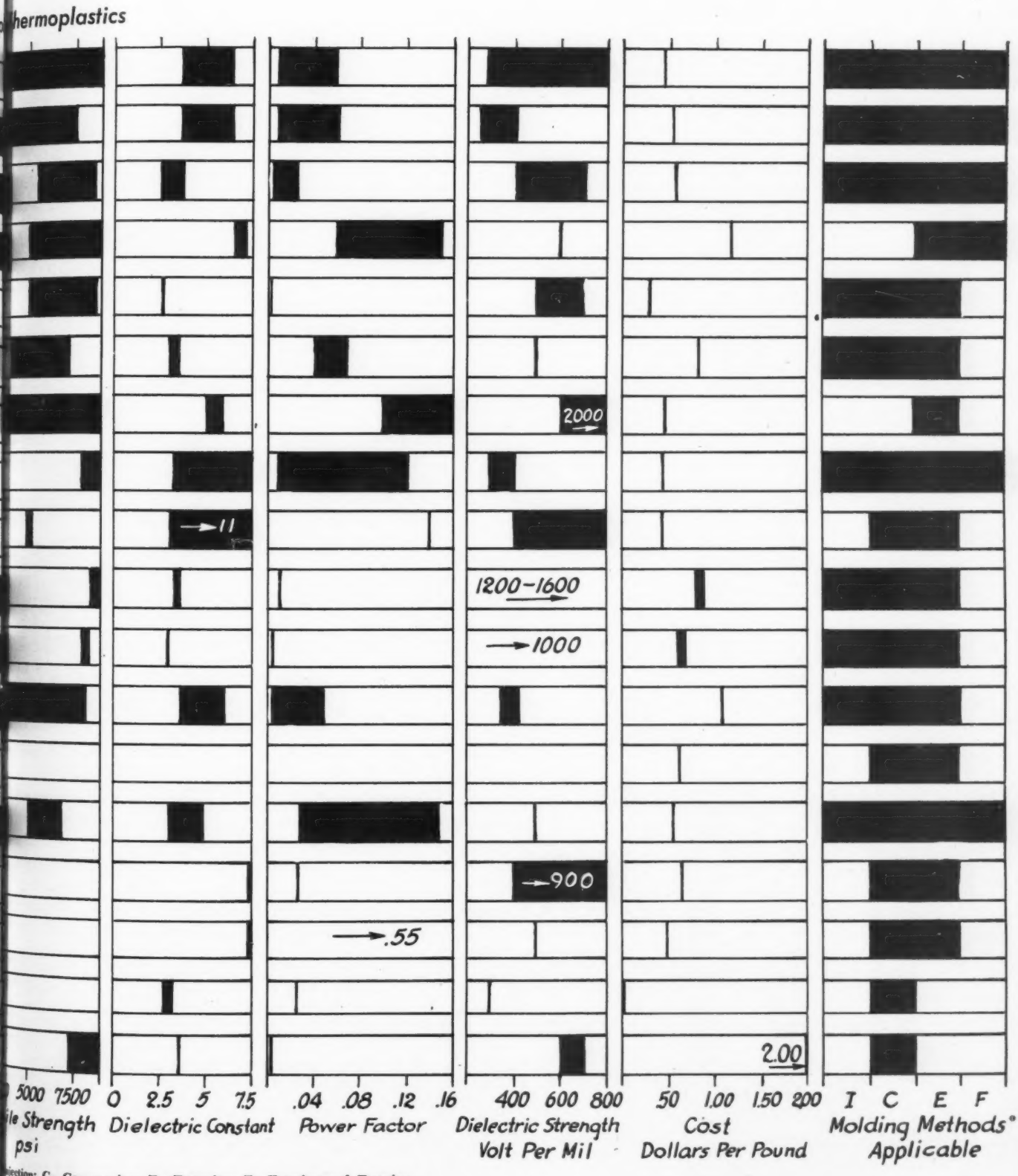


ties, lacking in natural rubber, are important. In electrical properties it resembles natural rubber.

12. ETHYLENE POLYSULFIDE (Thiokol): This also is a synthetic rubber with good resistance to solvents. It is used for covering wire and cable in locations where contact with solvents which would ruin ordinary rubber, is expected.

PINE TAR RESINS (Vinsol): These are dark-colored, brittle resins with little mechanical strength. They have good electrical properties and good resistance to oil and water. Their principal uses are in potting transformers, in cold moldings, and as a cheap adulterant or extender in other plastics.

ANILINE-FORMALDEHYDE RESINS: These resemble phenolic resins in many respects but are really thermoplastic materials with high softening points. They are restricted with respect to moldability but have good electrical properties and mechanical strength.



*jection; C—Compression; E—Extrusion; F—Forming and Drawing

Applications

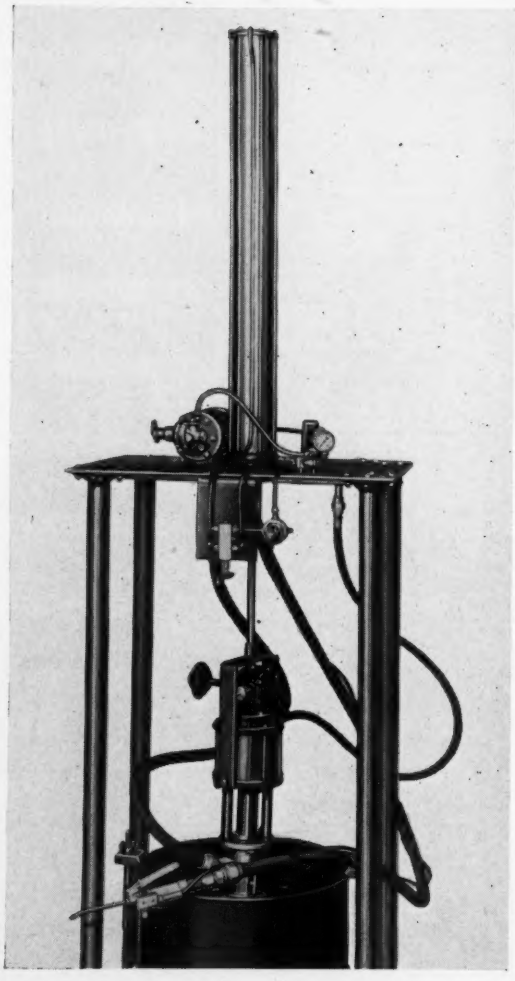
of Engineering Parts and Materials

Felt Flies High with Lightning Interceptor

REPLACING rubber on the Lockheed P-38 (Lightning), the felt pad on the cover door of the bomb shackle fairing, left, saves six-tenths of a pound of this critical material per plane. When the door is removed the bomb hoist support arm is free to swing outward into hoisting position. When the door is in place the felt pad holds the support arm folded securely inside the fairing. The pad, which conforms to Aeronautical Material Specification 3290, is cemented in place.

Drive Is Designed to Conserve Rubber

CONSERVATION of materials through the use of shorter center distances and larger sheaves is exemplified by the Allis-Chalmers shaper drive shown above, which uses the minimum practical amount of rubber and metal. With sheaves 5.2 inches pitch diameter, four belts are required. Use of a motor sheave less than 5 inches diameter would have necessitated employment of five belts with a corresponding increase in amount of rubber. To permit the use of only three belts the motor sheave would have had to be at least 7.4 inches diameter, and the corresponding driven sheave could not have been accommodated in the available space.



Pump Eliminates Priming Difficulties

CAPABLE of handling materials such as sealing compounds, sound deadeners, putty, and lubricants, the Lincoln air-driven induction pump permits transfer of materials directly from original container to point of application, as shown at left. Priming is accomplished by displacement instead of suction, the pump follower plate being held in contact with material by an air cylinder.

JOHNSON BRONZE

SLEEVE TYPE BEARINGS

Laurels for the PRIVATE SOLDIERS *of* INDUSTRY

● In the last war it was the "Fighting 69th." Today it's the "British 8th." Reports of successful battles carry the names of the *units* . . . and the commanding officers. Yet, the privates do the fighting.

In the battle of production, miracles are taking place every day. Some mechanical device . . . a machine tool . . . a giant press . . . a welding machine has changed our conception of what to expect in both quality and quantity of armament. These are the *units* of production. Hidden away in every mechanical unit are *bearings* . . . carrying the load . . . adding speed and precision . . . reducing friction. They are *The Private Soldiers of Industry.*

Johnson SLEEVE TYPE Bearings are doing their share. You can find them in every industry . . . in every type of mechanical unit. An extra measure of service built into every Johnson product enables them to quietly and efficiently establish new records of performance and bearing life.

When you are designing a new product . . . or improving an old one . . . consult with Johnson Bronze. We can help you select the *correct* bearing for each application. A Johnson engineer will assist you at your convenience. Write TODAY.

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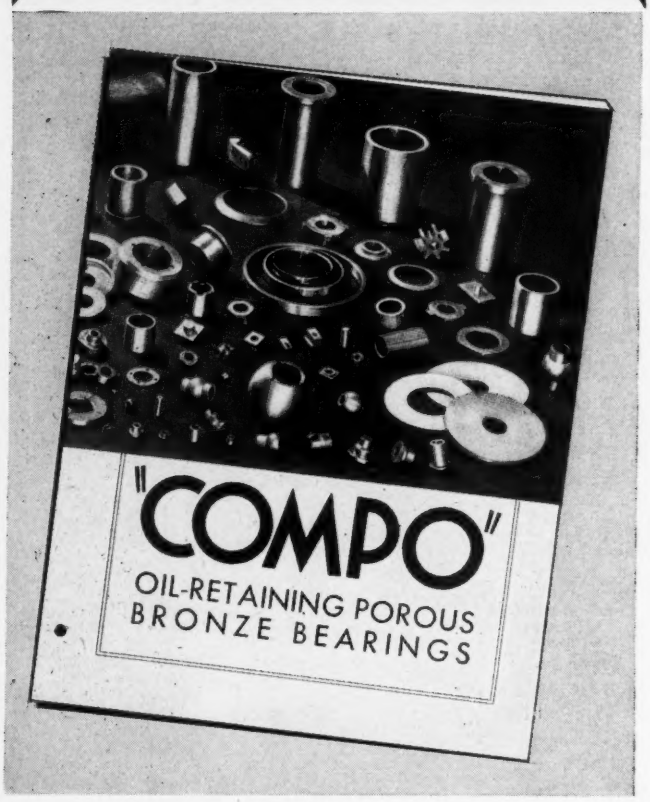

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FOR BETTER MACHINES AND APPLIANCES

PROFESSIONAL VIEWPOINTS

"... difficulties confront manufacturers"

To the Editor:

Referring to Mr. Cole's article "Worried About Specifications? Here's Washington Answer" in your May issue, I believe the author has done very well with the subject.

Some of the difficulties that have confronted and continue to confront many manufacturers who previous to the war program never made material for government agencies have been in securing and interpreting specifications, obtaining material in accordance with the specifications and securing authorization to make substitutions.

The article contains considerable information with which I was not familiar and which I feel confident is not general knowledge. It also clearly brings out why it would be impossible under existing conditions to work up a general cross index or equivalent specifications or permissible substitutions. However, the authoritative statement as to the procedure that must be followed in securing authorization for substituting materials is of some help at least in that direction. The multiplicity of specifications writing bodies which, as the article brings out, is further mushroomed as a result of the war program and the various systems of designing specifications has been one great source of confusion.

—R. G. De La Mater
The Parkersburg Rig & Reel Co.

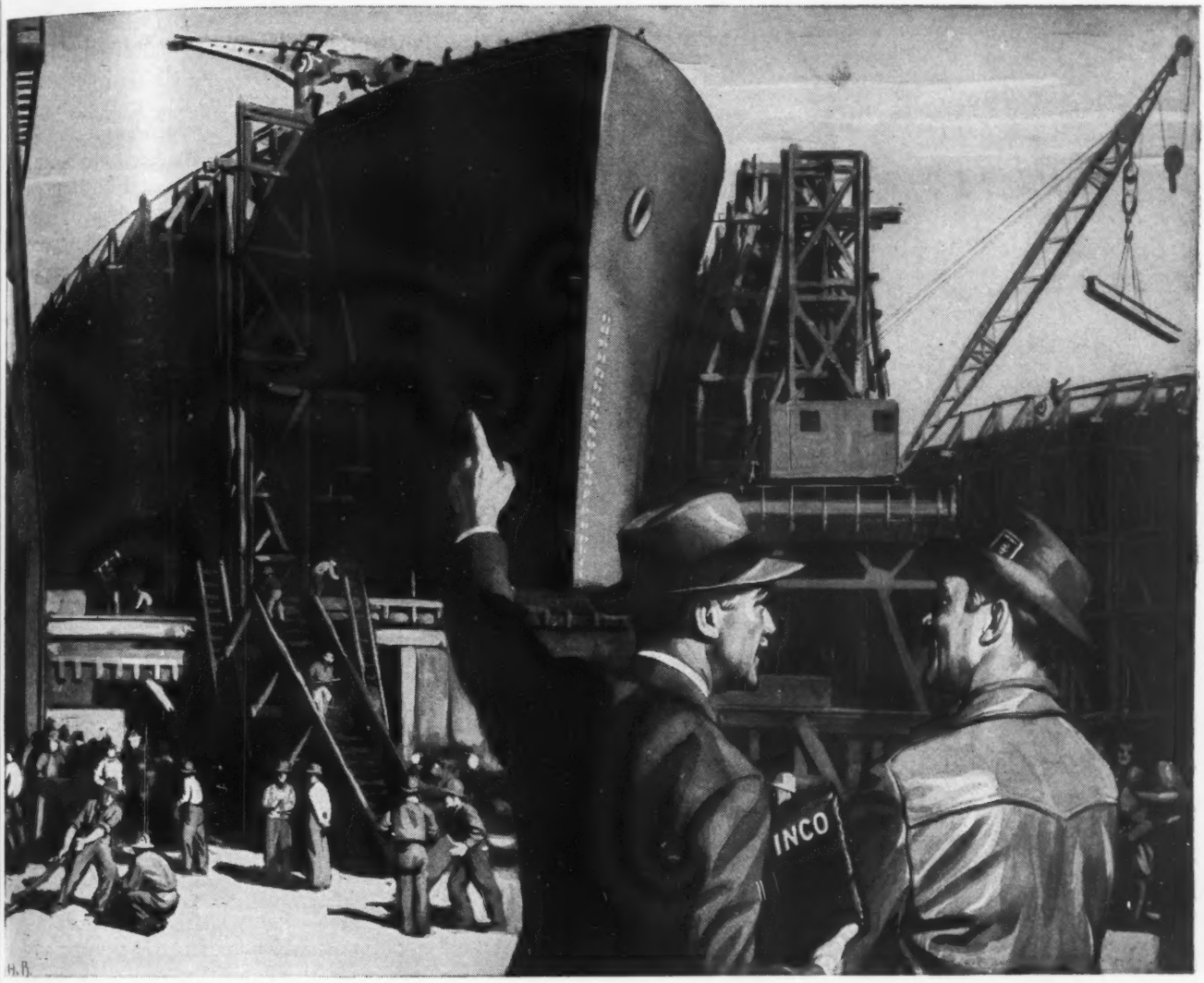
"... on specifications for government work"

To the Editor:

A great deal of confusion exists among manufacturers with respect to specifications for government work. I found this to be true during ten years of service on the engineering staff of the Navy Department in peace time and it is undoubtedly even more true under the present wartime stress. In the hope of being helpful to prospective government contractors I therefore offer the following:

In bidding, the allowance for government-specified materials need be only nominal, and particularly so since substitutions on the basis of equal or better strength are permissible at least where unavailable critical materials are concerned. It should be remembered, however, that both chemical and physical tests may be required, so that laboratory costs should be included in bidding.

Both the Navy and the Army departments have cut the country into a number of inspection districts each of which is in charge of a fairly high ranking officer. In addition, there are certain procurement and design approval agencies. For example, in the city of Cleveland the Supervisor of Shipbuilding stationed at the plant of the American Shipbuilding Co. is empowered to approve the designs of most of the Navy equipment to be deliv-



NICKEL AIDS THE MARINE INDUSTRY

to KEEP 'EM SAILING!

"Uncle *Needs* His Ships." That sign in a shipyard, a thousand miles from the sea, typifies the fighting spirit of America's ship builders. These men will turn out new tonnage faster than Axis bombs and torpedoes can sink it.

In peacetime, their engineering-thinking created efficient power plants that pushed ships of commerce through the seven seas. They designed propelling machinery—turbines, valves, pumps and gears—to move the ship and intricate instruments to guide and guard it on its important mission.

From turbine rotors to propeller shafts, from reduction gears to condenser tubes, those engineers relied upon ferrous and non-ferrous alloys strengthened and toughened by additions of Nickel. They used the properties of Nickel to fight corrosion and fatigue.

During wartime, when uninterrupted operation of America's bridge of ships means so much, the continued and widespread use of Nickel is convincing evidence of its many advantages. Now that sea-going metals must withstand repeated demands for stepped-up performance, a little Nickel goes a long way to insure utmost dependability.

Marine engineers and designers have long known and builders and fitters... as well as repair crews at bases 'round the globe... are learning that, properly used, a little Nickel goes a long way to "keep 'em sailing."

For years the technical staffs of International Nickel have been privileged to cooperate with the men who build and operate ships of all types. Counsel, and printed data about the selection, fabrication and heat treatment of Nickel alloyed materials, is available upon request.

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STANDARD Cannon Connectors are used in railroads, ships, television, sound apparatus, aeronautics, hospitals, power tools, lumber, machinery and geophysical research.

Irrespective of the purpose of your product, check with Cannon before you reach a decision that a special plug is needed. Connectors formerly thought of as *special types* are *standard* connectors in the Cannon line.

If your product will benefit by precision-built Connectors of unquestioned dependability, then you will be glad to know more of Cannon Connectors . . . Write for your copy of the Cannon Catalog Supplement. Address Dept. AE, Cannon Electric Development Co., Los Angeles, Calif.

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ered within his district, and in some instances designs originally approved by him will be accepted without further approval for machines to be delivered outside his district. Information as to by whom and where the plans are to be approved can be obtained from the procurement office, i.e., from the office to which the bids are sent.

If a would-be contractor has had general but not government experience with the sort of equipment he is planning to bid on, it is well for him to call on the approving agency to find out just what is wanted. The approving engineer will usually see the contractor's problem and will usually do all he can to help. As far as time permits he will explain just what is behind the necessarily terse specifications and he may show plans of machines similar to the ones now to be built.

Contacting the approving engineer before bidding gives the manufacturer the advantage of having made the acquaintance of a man to whom he can appeal both as to details of design and as to material substitutions. The approving engineer will in most cases be keenly conscious of the fact that it is of national importance for him to aid the contractor by expediting the work and if he is convinced of the contractor's sincere desire to do a good job he will do all he can.

But the contractor's problems are not solved when the plans are approved. The availability of materials shifts almost daily, and if he is to seek reapproval of plans because of the substitution of perhaps a better material for some part or parts, the contemplated substitute may not be available when the approval is received. He should therefore appeal to the local inspector rather than to the approval agency. Under a recent directive, inspectors have wide powers to authorize substitutions of materials and even changes in design which in their judgment serve sound engineering and manufacturing purposes.

The broad powers with which the inspectors are thus vested are primarily intended to expedite production without sacrificing quality of construction, and an inspector approached with that thought in mind is in a position to be of great service to the manufacturer.

—John Flodin
Elizabeth, N. J.

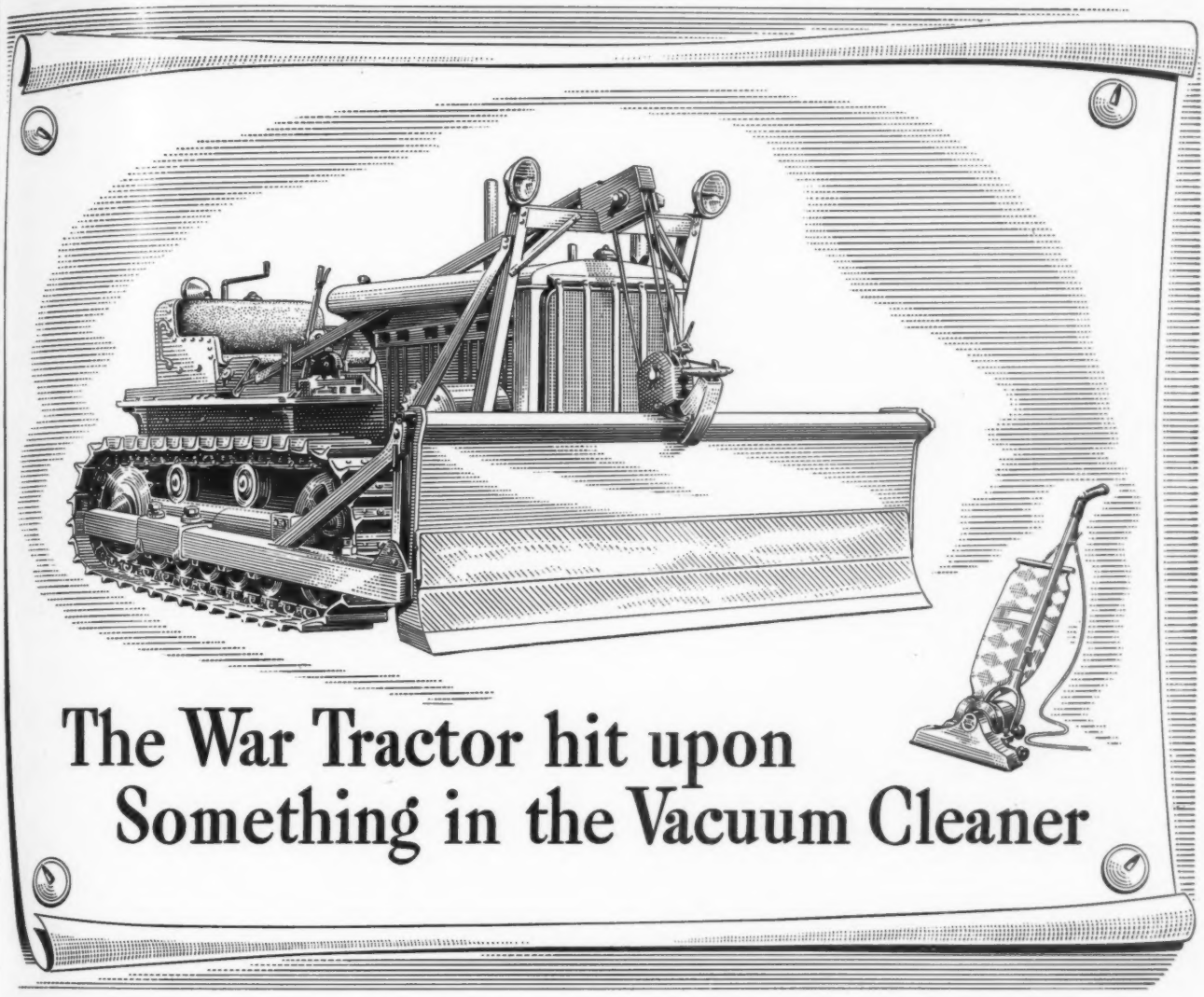
". . . more convenient than wall chart"

In our Engineering department no good place could be found to hang the usual type of decimal equivalent charts where they could be read easily. Decimal equivalents printed on celluloid strips were glued to the scales of the drafting machines.

It is no longer necessary to focus the eyes on a distant chart and then focus them back on the board. Eye-strain from reading figures at a distance is avoided.

Another time-saver used in this office consists of white plastic sheets on which standard units and motors of different makes have been drawn with ordinary drawing ink. A matte surface takes the ink easily and permanently. The outlines of the units and motors are quickly traced off on new layouts as needed, instead of slowly picking each dimension from a tabulated dimension sheet. Composites showing the outlines of all standard makes of motor on one sheet are especially convenient.

—G. D. Scott
The Heald Machine Co.



The War Tractor hit upon Something in the Vacuum Cleaner

ON THE FACE OF IT, a vacuum cleaner and a military tractor live in different worlds. The cleaner's job is a light-duty one—and what matters most is easy operation. That's why Torrington Needle Bearings were chosen for use in this household machine. With its low friction coefficient and compact design, the Needle Bearing is one of the reasons modern vacuum cleaners can be as easy to handle as a new broom.

The men who drive the tractors, on the other hand, are concerned chiefly with their ability to stand up under the most severe service conditions. But when a new bomber runway is wanted by dawn, or shell holes must be repaired while bombs are still falling, it helps to have a tractor whose mechanism responds quickly and smoothly. So tractor designers, too, turned to the Needle Bearing for long life and ease of operation... and found many other advantages as well. It seldom needs attention, thanks to an effective system of lubrication... it withstands overloading more easily, because of high load capacity... and it speeds tractor production, through its ease of installation and ready availability for essential applications.

SOMETHING TO KEEP IN MIND FOR POST-WAR. You'll soon be planning your post-war designs—or perhaps you've already started. There may be an idea for you in the Torrington Needle Bearing. Its advantages are the very features Tomorrow's customers are being educated to want—longer life, faster speeds, greater ease of operation, more compact designs, less need of attention. Whatever your design problems, let Torrington engineers help you. They are expert in adapting the Needle Bearing to specific applications. A long list of *typical* uses is included in Catalog No. 109.

NEEDLE BEARINGS FOR ALL PURPOSES

LOOSE ROLLERS are produced in a range of sizes for assembly into low-cost, high-capacity anti-friction bearing units. They are particularly adaptable to applications where volume permits installation of the necessary equipment.

NEEDLE BEARINGS are complete, self-contained units consisting of a full complement of rollers and a thin, hardened outer race. They offer the advantages of small size, low cost, high capacity—and are easily, quickly installed.

QUILL BEARINGS consist of a full complement of rollers and a relatively heavy hardened outer race. They are furnished with or without inner races. Quill Bearings are adaptable to heavier load requirements than Needle Bearings.

THE TORRINGTON COMPANY

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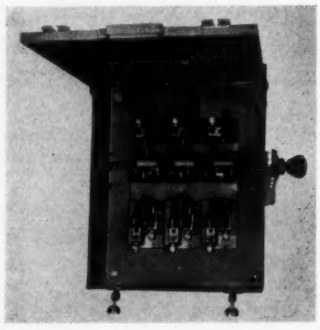
TORRINGTON NEEDLE BEARINGS

New PARTS AND MATERIALS

Double-Throw Switches

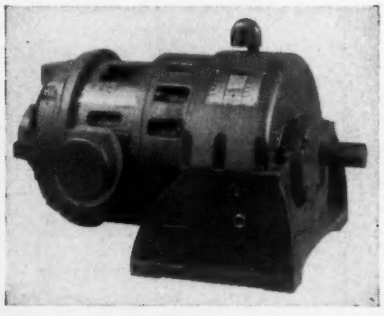
BUILT to government requirements, a new line of double-throw switches has been developed by Square D Co., 6060 Rivard street, Detroit. Marine type switches, they are splashproof and designed to withstand shock tests as specified by the Navy. They are available



in 2 or 3 pole, from 30 to 100 amperes, 250 volts alternating current, 250 volts direct current, and 575 volts alternating current, fusible or not fusible types. The 575 volt alternating-current switches have 250 volt (Navy) fuse spacings.

Horizontal Gearmotors Redesigned

HORIZONTAL parallel shaft type gearmotors of Westinghouse Electric & Mfg. Co. meet speed reduction requirements of a wide variety of industrial applications. Range of the units is 1 to 75 horsepower. Conforming to A.G.M.A. standard output speeds and ap-



plication practices, the new gearmotors feature compactness and improved foundation stability through the heavy exterior ribbing of the housing at each mounting hole. Use of adaptor castings between motor and mechanical parts permits utilization of standard N.E.M.A. frame motors with each type of unit, and the types of motor construction can be readily changed to suit varying service conditions if necessary in the field. The design of the motor-adaptor assembly being common between unit types, such assembly can be readily shifted to meet any desired changes in speed requirements. Many of the working parts including gear seats being common to all three unit types of a given rating, replacement of parts is held to a minimum. Gears and pinions of .40-.50 carbon steel are given special heat treatment before hobbing, which produces a tapering hardness from surface to core and results in tough, impact resisting teeth. Lubrication of gears and bearings is by a positive splash system, the new case design allowing oil to circulate freely at all times.

Air Speed Control Valve

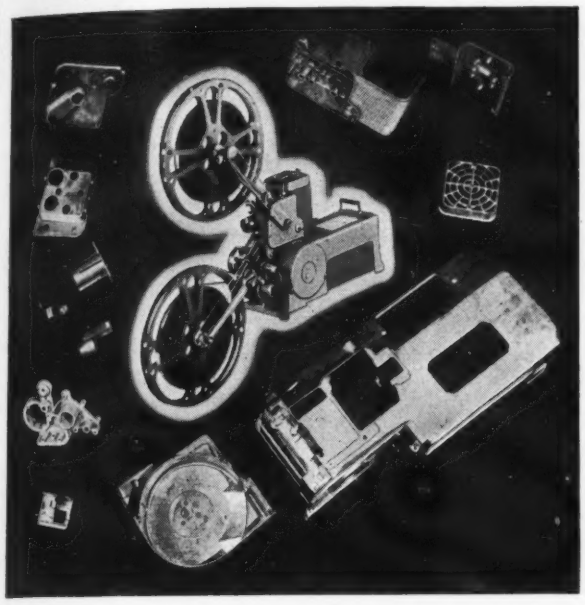
PROVIDING and maintaining accurate split-second timing of piston movements, an air speed-control valve has been announced by Ross Operating Valve Co., 6485 Epworth boulevard, Detroit. Starting with full capacity flow in both directions, the flow in one direction can be controlled over a wide range to a completely closed position. Through a vernier-like adjustment mechanism a greatly increased range of selective speeds may be obtained. The valve has a specially designed stem and floating bevel seat poppet which maintains a positive, steady control at any selected speed.

Hydraulic Foot Pumps

SELF-CONTAINED piston type, single and two-speed foot pumps have been introduced recently by Lyon-Raymond Corp., Greene, N. Y. Entire mechanisms of the pumps are contained within the oil reservoir. On the single-speed foot pump the large pedal is used for elevating pumping on the down stroke only. The small pedal to the left is for release, the speed of which depends upon the amount of depression of the pedal. Approxi-

FOR WAR TODAY—FOR YOUR PRODUCTS TOMORROW

A DIE CAST PROJECTOR FOR SERVICE FILMS



Most of the castings can be identified on the projector

One of the country's leading producers of motion picture equipment is now turning out special sound projectors for the exclusive use of the armed forces. Motion pictures are a "must" in this war for training—and for entertaining—service men. Says the Commanding Officer in Iceland: "Motion pictures are as necessary to the men as rations."

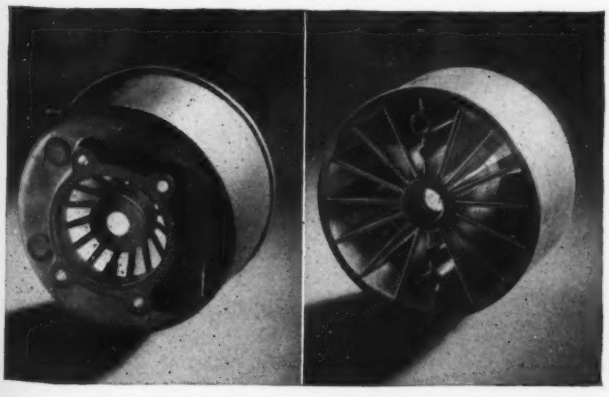
As is evident from the zinc alloy die cast parts grouped around the complete assembly in the above illustration, the new projector is practically all die cast. Here you see the inherent advantages of zinc alloy die castings fully utilized —economy, complexity, accuracy and strength.

This item deserves a place in your post-war product planning file.

HOW WOULD YOU PRODUCE THIS PART?

We would like to be able to place the part illustrated below in the hands of every design engineer in the country. It is an outstanding example of the ability of the die casting process to produce unusual shapes in one piece—in zinc alloy.

The photograph gives sufficient detail—in lieu of examining the actual part—to ask "How else could it be produced at comparable cost?" As cast in zinc alloy the part is 3¼" in diameter, and weighs 1 lb. 6 oz. Its use?—that's a military secret.



One piece construction—front and rear views

LESS MACHINING WITH DIE CASTINGS

Because of the complexity of form, the accuracy of detail, and the smoothness of surface obtainable in zinc alloy die castings, the parts so produced usually require little or no machining. There are many instances where a simple trimming operation to remove flash metal is all that is necessary to put the castings in service.

When machining is required, however, the free-cutting zinc alloys insure easy, rapid metal removal—with long tool life. For full information on current machining procedure with zinc alloy die castings, write for a copy of the bulletin "Practice In Machining Zinc Alloy Die Castings."

For many applications, only this trimming is necessary

THE New Jersey Zinc ALLOY POT

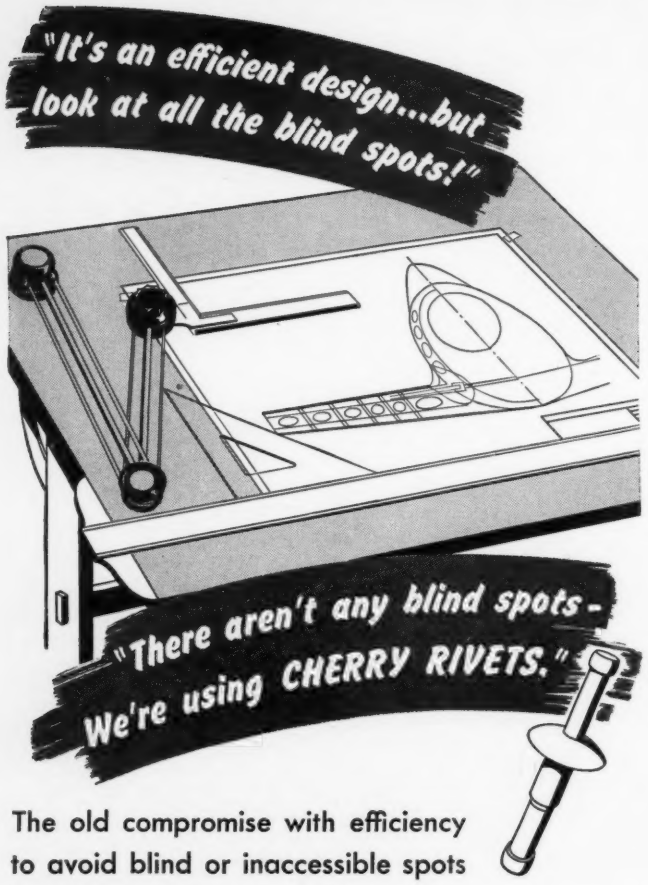
A publication issued for many years by The New Jersey Zinc Company to report on trends and accomplishments in the field of die castings. Title Reg. U. S. Pat. Off.

MACHINE DESIGN EDITION No. 9

FOR VICTORY BUY UNITED STATES WAR SAVINGS BONDS STAMPS

THE NEW JERSEY ZINC COMPANY 160 FRONT ST., NEW YORK CITY

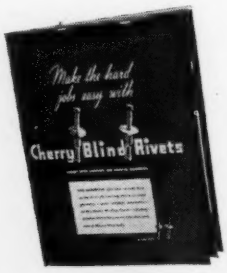
HORSE HEAD SPECIAL (99.99 + % Uniform Quality) ZINC



The old compromise with efficiency to avoid blind or inaccessible spots in airframe structures has been eliminated by the Cherry Blind Rivet.

This mechanical blind rivet has proved itself in thousands of aircraft and due to its high shear and fatigue values is opening new doors for the engineer. He can now design *up to* efficiency rather than *down to* a manufacturing limitation.

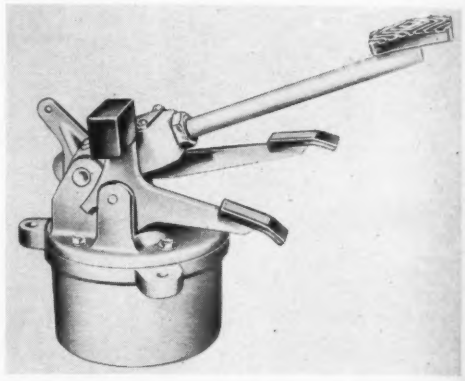
The complete story on Cherry Rivets is available. Request your copy of the new Handbook A-43 from Department 8, Cherry Rivet Company, Los Angeles, California.



CHERRY RIVETS, THEIR MANUFACTURE AND APPLICATION ARE COVERED BY U. S. PATENTS ISSUED AND PENDING.

Cherry Rivet Company
LOS ANGELES, CALIFORNIA

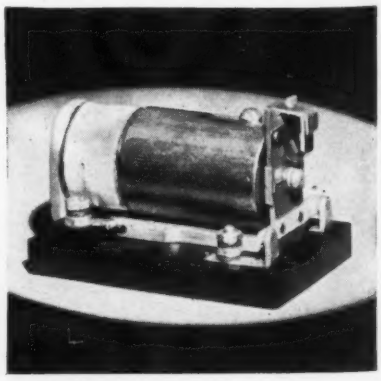
mately 35 strokes for 14-inch elevation is necessary. The two-speed foot pump, shown in the illustration, is similar to the single speed, except that the release pedal is to the right of the pumping pedal. The small pedal to the left of the pumping pedal is for changing from low to high speed. In the high-speed position, the pump doubles the volume pumped in low-speed position. Large pedal in



the center is used for elevation, pumping on the down stroke only. Approximately 35 strokes for 14-inch elevation is required in low-speed position and 18 strokes for 14-inch elevation in high-speed position. In the high-speed position the table elevates at twice the speed as in the low-speed position but takes twice the effort with the same load. This high speed is advantageous with loads of half the rated capacity or less.

Aircraft Time-Delay Relay

SPECIFICALLY designed for aircraft applications where time-delay drop-out is a requirement, a new relay has been made available in two sizes by General Electric Co., Schenectady, N. Y. One size provides up to .4-second time delay and the other up to .3-second time delay. This relay on many applications can be used directly to control the desired device, while on others it may



be desirable to have the relay actuate a contactor. The principle employed to accomplish the accurate time delay consists of delaying the decay of flux in a magnetic circuit through the use of a single-turn, low-resistance copper jacket around a section of the magnetic structure. Both

(*Continued on Page* 150)

This "MAGIC BRAIN" knows where "Fritz" will be at 3:42 91/1000 P.M.

Ask Anyone in Industry!

WHEN the enemy's winging in at 300 miles an hour or better, shooting "where he is" only throws shells away. You have to know where he's *going to be* by the time the answer can be figured, the gun aimed, and the shell hurled miles into the sky.

Give a mathematical genius some instruments, a slide rule, and enough time, and he could tell you—too late—where the gun *should* have been aimed. But this "gun with a brain" doesn't need time. Just show it where Fritz is, and—wham!—a string of shells is on the way to *where he will be,* figured to split fractions of a second by a "brain" no human can match!

One thing could easily upset this whole deadly operation. If any single part became worn or balky through lack of care, shells might wing far from their mark and the enemy go unscathed on his mission. That's why Alemite Lubricating Systems help guard the accuracy of these amazing guns—and why gun crews are carefully trained to give that system the right lubricants at the right time.

THE MACHINES you design must hit a mark, too—a new high mark in performance and trouble-free satisfaction. You want to avoid service calls, because service men are scarce and replacement parts are well-nigh unobtainable. The right lubrication system can make a tremendous difference!

That's why the vast majority of machine designers in many fields make Alemite Lubrication Systems standard on their machines—because Alemite Fittings insure clean, fast, positive lubrication for every bearing. There is an Alemite Lubrication Engineer near you who will be glad to offer suggestions—without obligation. For quick action, wire or phone us direct.

FREE! Two important books "Alemite Industrial Lubrication Manual" and the latest catalog of Alemite Industrial Lubrication Equipment. Write for them today!

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Another Product of

STEWART WARNER

Here's What You're Fighting For...

. . . your way of life! Every man interprets it a little differently, but to us all it means a car, a radio, a refrigerator; the right to those things that make our daily life pleasanter, more convenient, more exciting. Today Weatherhead plants are producing vital parts for planes, tanks, ships, trucks and munitions at the rate of *millions every twenty four hours.* The coming of Peace will find us prepared to join with you in building durable goods the world will want as well as many strange new devices being born in the war.

Look Ahead with Weatherhead

THE WEATHERHEAD CO., CLEVELAND, OHIO
Manufacturers of vital parts for the automotive, aviation, refrigeration and other key industries.

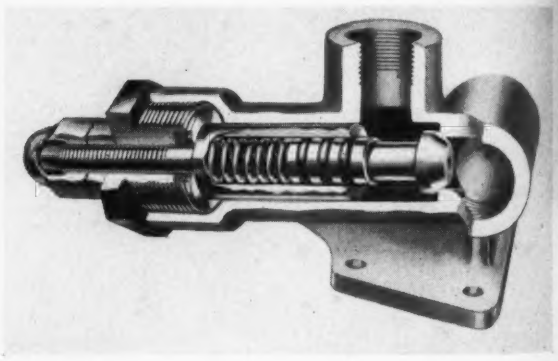
Branch Offices:
Detroit, Los Angeles, New York and St. Louis

(*Continued from Page* 144)

sizes of the relay are compact and suitable for mounting in any position. Designed for use in a wide range of ambient temperatures—from 95 degrees Cent. to —40 degrees Cent.—the corrosion-proof relay withstood 95 per cent humidity at 75 degrees Cent. on 48-hour tests and operated successfully immediately thereafter. Normally closed, double-break, silver contacts will carry 20 amperes continuously at altitudes up to 40,000 feet above sea level. Operating coils are available for operation on either a 12 or a 24-volt circuit. Contacts will remain in correct position without chattering, whether the relay is energized, or de-energized, even when subject to mechanical frequencies of from 5 to 55 cycles per second at 1/32-inch amplitude (1/16-inch total travel), applied in any direction, or when subjected to linear acceleration of ten times gravity in any direction.

Self-Stabilizing Relief Valve

RECENTLY perfected and now being offered by Merit Engineering Inc., 40 Clifford street, Providence, R. I., is the self-stabilizing relief valve. Based on hydraulic balance, the valve requires one light spring to give a range in pressure control from zero to 3000 pounds. Regardless of the variations in pump speed, the pressure



gage remains constant. Structural strength with less weight, and maximum efficiency with fewer working parts are provided. The valve is so designed that problems of vibration, noise and chatter are eliminated. Parts are interchangeable—a time-saving feature of the valve.

Electronic Adjustable-Speed Drive

FEATURES of the new electronic adjustable-speed drive developed by Westinghouse Electric & Mfg. Co., East Pittsburgh, include stepless speed control, automatic close speed regulation over wide load fluctuations, full torque at extremely low speeds, smooth stepless acceleration and deceleration and dynamic braking. This new drive, known as the Mot-O-Trol, is for application on industrial drives such as machine tool feeds, winding reels, conveyors, and fabricating and converting machinery. It is available for ratings up to 1 horsepower for single phase operation on 110 or 220-volts, 60-cycle systems. Where required, special drives of larger horsepower rating can be designed. The new drive has four parts: Power trans-

Die spring failure can be checked

Information supplied by an Industrial Publication

A recent investigation of die spring breakage developed the following prominent causes:

1. Hydrogen embrittlement resulting from plating, pickling or cleaning.
2. Incorrect die design.
3. Incorrect spring size.
4. Speed of compression cycle.
5. Poor quality of wire.

There are, fortunately, remedies for all these conditions. Hydrogen embrittlement can be corrected by heating plated springs to about 450°F. and air cooling.

Faults in die design usually consist of either insufficient or too great clearance between the outside diameter of the spring and the guide hole. The clearance should be such that the spring operates freely, but has no chance to buckle.

Care should be taken in selecting springs to see that they are properly designed for both length of compression stroke and speed of compression. If springs are repeatedly compressed too close to their solid height, quick failure will result. The same is true where the rapidity of compression is too great.

It seems obvious that the quality of the spring wire should be commensurate with the job. Cheap wire should be avoided because of defects that are bound to cause trouble, especially when springs are plated.

CLIMAX FURNISHES AUTHORITATIVE ENGINEERING DATA ON MOLYBDENUM APPLICATIONS.

ARMY E NAVY

MOLYBDIC OXIDE, BRIQUETTED OR CANNED • FERROMOLYBDENUM • "CALCIUM MOLYBDATE"

Climax Mo-lyb-den-um Company

500 Fifth Avenue • New York City

MOLY

"IF YOU HAVE A TOUGH JOB HANDLING VISCOUS LIQUIDS"

Here's Your Pump

A BLACKMER ROTARY

IT IS SELF-ADJUSTING FOR WEAR

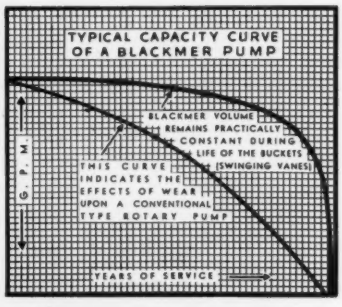
4 STANDARD CONSTRUCTIONS

Unlined for oils, syrups, etc.
With removable liners for corrosive or mildly abrasive liquids.
Steam-jacketed for extreme viscosities.
Or with both removable liner and steam-jacket.

A positive displacement pump that handles economically any clean liquid that flows through pipes.

SUSTAINED CAPACITY

No loss due to internal wear. Bucket Design makes this pump self-adjusting for wear. When the buckets wear out, they are replaced in 20 minutes and the pump restored to its original capacity.


TYPICAL CAPACITY CURVE OF A BLACKMER PUMP
BLACKMER VOLUME REMAINS PRACTICALLY CONSTANT DURING LIFE OF THE BUCKETS [SWINGING VANES]
THIS CURVE INDICATES THE EFFECTS OF WEAR UPON A CONVENTIONAL TYPE ROTARY PUMP
G.P.M.
YEARS OF SERVICE

CAPACITIES 5 to 750 GPM—PRESSURES TO 300 psi
Liquid temperatures up to 600° F.
HAND PUMPS MADE IN 54 STANDARD MODELS
Capacities from 7 to 25 GPM

BLACKMER NATIONWIDE ENGINEERING SERVICE
awaits your call on problems involving rotary pumps.

BULLETINS FREE TO DESIGN ENGINEERS

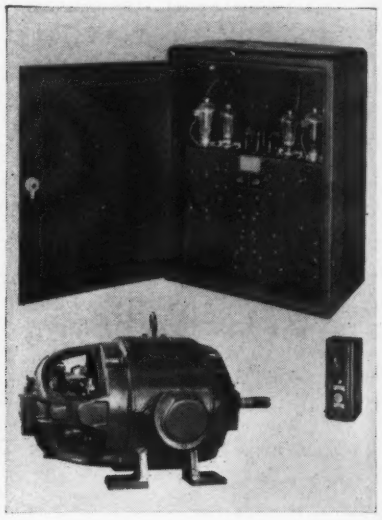
No. 301 — Facts about Rotary Pumps
No. 130 — 24 page General Catalog
No. 302 — Pump Engineering Data

Write Blackmer Pump Co., 1976 Century Ave., Grand Rapids, Mich.

BLACKMER Rotary PUMPS

"BUCKET DESIGN"—SELF-ADJUSTING FOR WEAR

former for separate mounting, cabinet with thyratron tubes and current limiting and speed regulating control, control station with potentiometer to vary voltage supplied to the armature and field circuits, with start and stop pushbuttons, and shunt-wound direct-current motor. It is designed to regulate automatically a preset motor speed,



regardless of load. The direct-current voltage output of the main rectifier tubes is controlled by small tubes to compensate for speed changes. For a speed range of 10 to 1 with torque varying from no load to full load, speed will not vary more than 4 per cent from the preset value. Maximum variation for the 20 to 1 speed range is within 8 per cent.

Percentage Timer Offered

FOR automatically controlling the percentage of time at which any alternating-current circuit can periodically be closed or opened out of a definite length of a time cycle, a new percentage timer is being offered by The R. W. Cramer Co. Inc., Centerbrook, Conn. It is particularly applicable where one function bears a definite time relation in percentage of operation of a second function such as regulation of input to electrically operated furnaces, ovens or heaters and control of the proportionate flow of chemicals for boiler feed water treatment, etc. The timer has a self-starting synchronous motor. This drives a cam-operated switch mechanism through the medium of an enclosed gear train. Percentage of operating time is a function of the motor-driven cam in relation to a similar stationary cam fixed to a calibrated dial. Varying the position of a stationary cam alters the rela-

OWI Photo by Palmer, in an Allegheny Ludlum plant.

ALLOY AMMUNITION DUMP

FOR THE WAR MATÈRIEL BUILDERS

COILS of strip and stacks of sheet bars—Allegheny Ludlum Stainless and Electrical steels—how well the United Nations will use them.

As illustrated, these alloy steels are in the hot-rolled state. They're still a raw material. A great deal of careful and often highly involved processing—hot and cold-working, annealing, pickling and surface-finishing—must be done before they'll be ready to take their places on the war lines. But one day soon—correct to the exact physical, chemical or electrical properties required of them—these alloy steels will take their places in the planes, tanks, guns and ships of the fighting fronts. And always, it is a most essential and important place.

High-alloy steels are not ordinary materials. They are not produced, nor can they be used, in ordinary fashion. Above all, they must not be wasted through faulty selection, undue scrap losses, too high a percentage of rejects and spoilage, or any other reason that would prevent a fabricator from getting the maximum amount of war matèriel from every ton of alloy steels he uses.

That's both your and our responsibility, and we want to help in any way possible. Complete technical and fabricating data is available on all Allegheny Ludlum grades, as well as the personal assistance of our Technical Staff.

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STEEL CORPORATION
BRACKENRIDGE, PENNSYLVANIA

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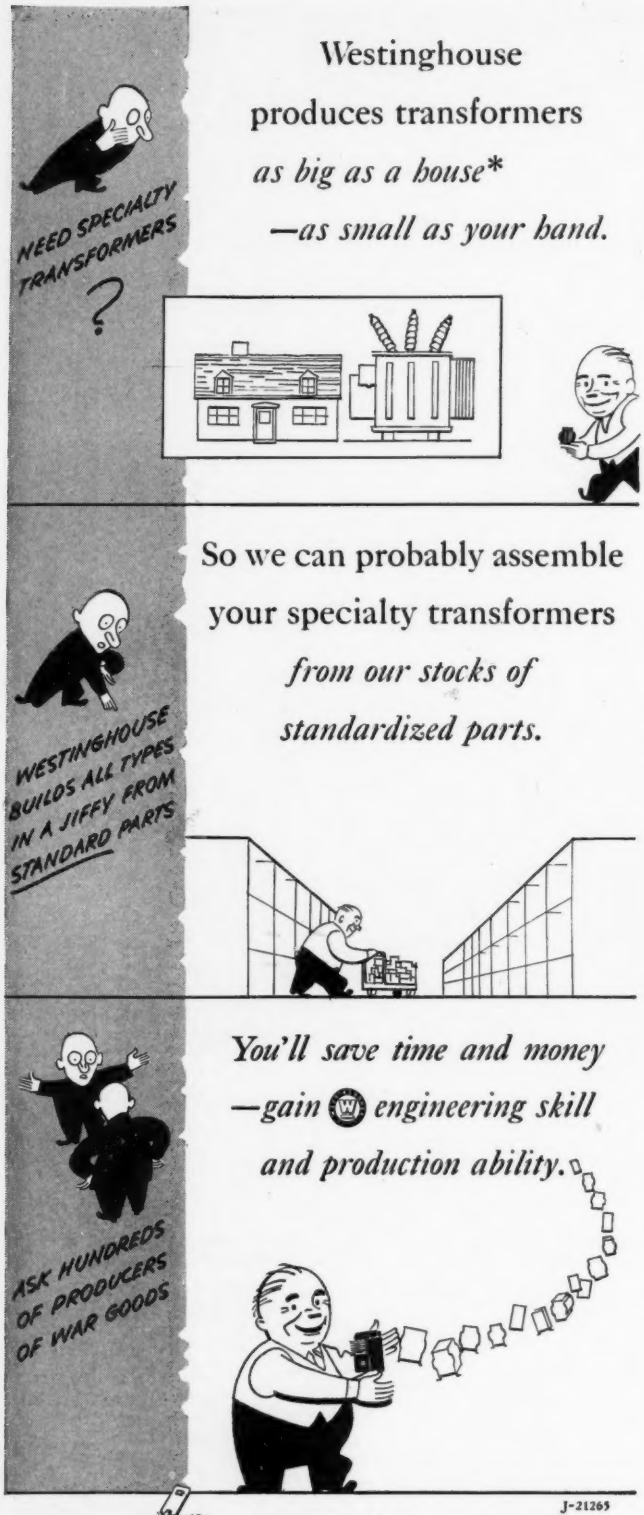
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produces transformers
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from our stocks of
standardized parts.
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You'll save time and money
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and production ability.
ASK HUNDREDS OF PRODUCERS OF WAR GOODS
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QUICK! WRITE FOR FULL DETAILS
*Two are now helping produce more aluminum. Each is the size of a six-room house, weighs 627 tons!
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DEPT. 7-N., WESTINGHOUSE ELECTRIC & MFG. CO., EAST PITTSBURGH, PA.
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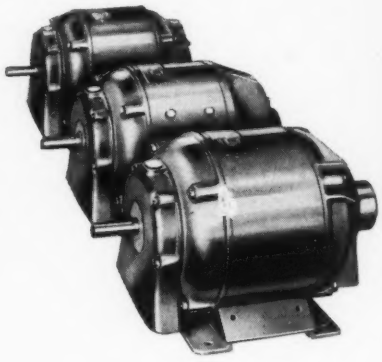
tion between the contact mechanism and opens and closes it a definite percentage of the total cycle indicated on dial. Available for seven different time ranges from 30 seconds to 60 minutes total cycle, the timer has a single-pole, single-throw contact rated at 10 amperes at 115 volts or 5 amperes. Enclosed in a dust-tight molded bakelite case for flush mounting, the timer measures 3¼ inches in diameter and 3-9/32 inches in overall length, and can be furnished with various types of surface mounting steel connection boxes.

Motors Are Interchangeable

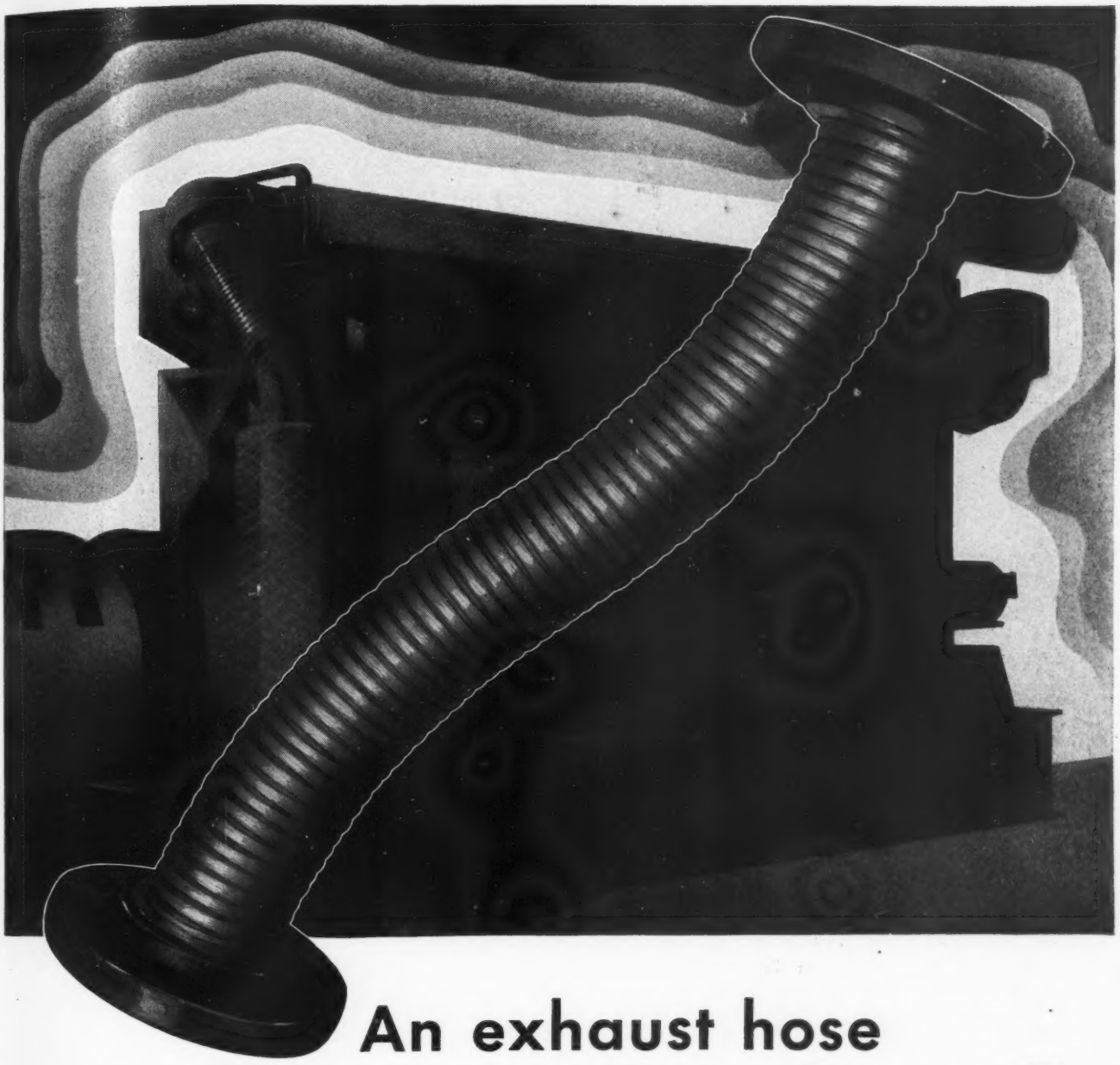
NEW uniformity in construction of electric motors announced by Robbins & Myers Inc., Springfield, O., provides interchangeability of all motor types in any one frame size. Known as Uni-Shell motors, they are built within cylindrical shells of steel, and in any one frame size the shell dimensions, head fit, bolt circle holes, shaft size and conduit box mountings are identical for all motor types. Except for the slightly different end heads necessary to different motor types, dimensions are identical in any one frame size. Embodied also are other improvements that contribute to longer motor life, dependability and efficiency. Double-row-width ball bearings are stand-



ard on all ball bearing motors. They have large grease reservoir and complete seals on both sides held in place by removable snap rings. Improvements have also been made on sleeve bearings for motors requiring them. Cast bronze bearings with highly finished surfaces are used on both wool-packed and ring-oiler types. To provide good insulation the company has utilized the best insulating materials, incorporating the newer synthetic varnish treatments. Air flow is also provided to cool the motors. Good bearing alignment and rotor construction, together with precision balancing, prevent vibration. Three grades of rotor balance are available on all types of Uni-Shell motors: Static balance, commercial dynamic balance, and special dynamic balance.

Thermostatic Bimetal

COMBINING high electrical resistance with a high thermal deflection rate, a new thermostatic bimetal is being produced by W. M. Chace Co., 1616 Beard avenue, Detroit. Designated as Chace No. 6850, the new



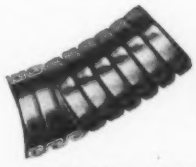
An exhaust hose that isn't easily "exhausted"

Once installed, American Diesel Engine Exhaust Hose stays on the job for years ... absorbing vibration, providing permanent tightness against seepage, deadening noise, compensating for expansion and contraction caused by the terrific temperature changes encountered in exhaust lines.

Here's why American stands up so well in this unusually severe service: essentially this hose is a flexible pipe. Made of heavy galvanized steel, it is spirally wound so that each convolution becomes fully interlocked with the next. A continuous packing, fed into a prepared groove, insures permanent tightness. And because it's flexible, it's easy to install. American also furnishes flexible metal tubing for fuel, air and starting lines on Diesels.

In addition to Diesel duty, many other types of American Flexible Metal Hose and Tubing serve war industries with distinction, some by conveying oil, steam, gas and water; others as a vacuum service for removing filings and dust, as protective armor and to shield electric wires, and in a thousand and one other important applications.

Whatever your needs in metal hose or tubing, you'll likely find one in the American line that will help you do the job just a little bit better. Your inquiries are invited. 43201



American Interlocked — wound of strip metal, joints packed; the toughest type of extremely flexible metal hose.

AMERICAN METAL HOSE BRANCH OF THE AMERICAN BRASS COMPANY
General Offices: Waterbury, Connecticut
Subsidiary of Anaconda Copper Mining Company
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ANACONDA "from mine to consumer"

American Metal Hose

This is no time to take chances with war production

This year calls for a supreme effort on the part of every manufacturer engaged in war production to deliver the goods—to get there "fustest with the mostest"—and whatever tools of war are sent must be the finest that skilled American workmen can produce. This is no time to take chances with your war products.

DU-LITE Black Oxide Steel Finish has long demonstrated its superior qualities—its uniformity—its remarkable characteristics as a rust preventative—its aid to lubrication—its economical, fast application.

Where there are steel parts to be finished Du-Lite will prove its value. This statement is based on the experience of hundreds of leading manufacturers throughout the country, producing aircraft, tank and marine engines, arms, bomb parts, cartridge clips, instruments, tools and machine parts.

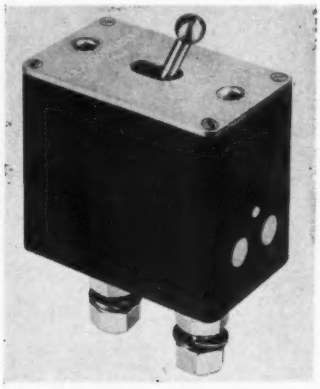
Without question, if you want your product to measure up to the most rigid specifications, use Du-Lite for the finish.

DU-LITE CHEMICAL CORP.
MIDDLETOWN, CONNECTICUT

material is intended primarily for thermostatic resistors which operate as a result of the heating effect of the current. Present applications range from flashers to motor overload protection, including particularly the newer circuit breaker designs. Electrical resistivity is 850 ohms per circular mil foot, or 668 ohms per square mil foot, at room temperature. Deflection rate is practically uniform between 0 and 400 degrees Fahr., and slightly lower above and below this temperature. At temperatures as low as 100 degrees Fahr., operating characteristics are said to remain constant.

Circuit Breakers for Aircraft

AVAILABLE in capacities of 80, 90, 100 and 125 amperes at 30 volts direct current, the new circuit breakers announced by Square D Co., 6060 Rivard street, Detroit, supplement the company's line of 9300 aircraft circuit breakers which had a maximum capacity range of 5 to 70 amperes. While these breakers are primarily designed for aircraft, their nontrip free, vibration-proof and lightweight factors have made them popular for use in tanks, boats and other mobile equipment. They may



be used for direct control of electric motors, lighting circuits, communication and signal systems or fire control installations. The combination of toggle and circuit breaker in a single sealed unit saves weight, space and wiring time. Calibrated and factory sealed, with no field adjustments necessary, the breakers have been vibration tested in accordance with Air Corps specifications. Acceleration tests indicate that a force of 10g's does not cause malfunctioning. Proper operation can be obtained at ambient temperatures of from —50 degrees Fahr. to 135 degrees Fahr.

Lightweight Thyratron Tube

FOR application in industrial welding and any general control equipment where weight and space must be considered, a new thyratron tube with both a control and a shield grid for control applications, has been developed by General Electric Electronics department, Schenectady, N. Y. The new tube, known as the GL-502, is a little over 2½ inches long, weighs about 2 ounces, is inert-gas-filled and of all-metal construction. Control characteristic is practically independent of ambient temperature over a

You Name the Part—

Probably we make it

Brake Shoe **MAKES PARTS** for original equipment and for maintenance; parts that are upset and drop forged; molded fabrics and plastics; ferrous and non-ferrous castings. In war, as in peace, Brake Shoe ships millions of parts to thousands of manufacturers, in many fields of industry.

The services of our research and development engineers are available for immediate or post-war problems.

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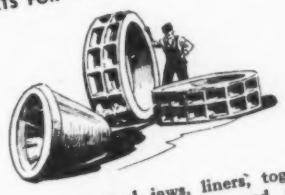
PARTS FOR — CARS, TRUCKS

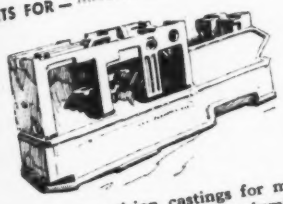
Brake lining, clutch facing, fan belts, radiator hose, axles, shafts, gear blanks and engine part forgings.

PARTS FOR — CRUSHERS

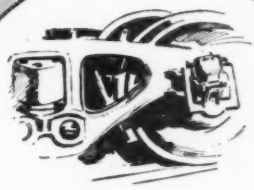


Manganese steel jaws, liners, toggle seats, mantles, conveyors and roll shells. Bearings and babbitt metals.

PARTS FOR — MACHINE TOOLS



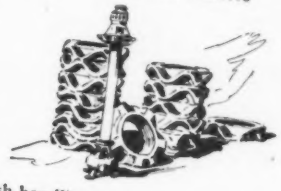
Meehanite precision castings for machine tool bases, beds and columns. Sprockets. Bronze bushings.



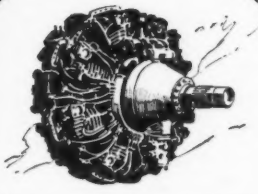
PARTS FOR — RAILWAY EQUIPMENT

Brake shoes, lockeys. Chilled tread car wheels. Car and locomotive wearing parts. Axle or journal bearings.

PARTS FOR — POWER PLANTS



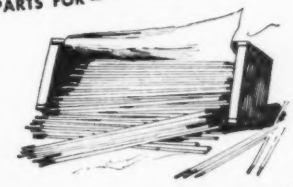
Ash handling pumps. Manganese steel pulverizer and grab bucket parts. Alloy steel superheater parts.



PARTS FOR — PLANE ENGINES

Forgings for cylinder barrels, crank shafts and connecting rods. Bearings for starter and camshafts, fuel pumps.

PARTS FOR — WELDING



Welding products for reclamation, hard surfacing and repair of ferrous equipment parts. Welding rods, flux.

PARTS FOR — HEAT TREATING

Chromium nickel alloy boxes, pots, pans, trays, hearth plates, chain, rails, muffles and retorts.

58 PLANTS SERVING INDUSTRY AND TRANSPORTATION

American Brakeblok Division	*Detroit, Mich.*
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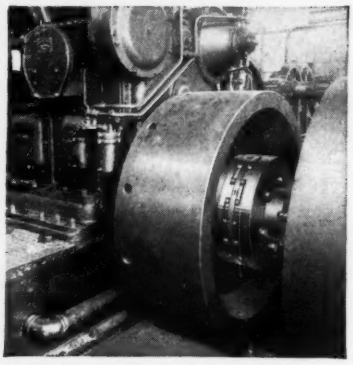
Kellogg Division	*Rochester, N. Y.*
American Forge Division	*Chicago, Ill.*
Southern Wheel Division	*New York City*
National Bearing Metals Corp.	*St. Louis, Mo.*

AMERICAN **Brake Shoe** COMPANY

Most Efficient Protection Against
MISALIGNMENT
WHIP CHATTER
BACKLASH
OSCILLATION
REVERSING
LOADS
PULSATING LOADS • • • • OVERLOADS

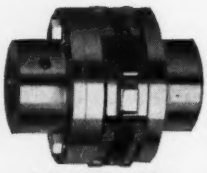


Transmits Maximum Power

Free-Floating Cushions hung between rugged jaws, or held by removable steel collars or retainers. Transmit full power flow, while free to adjust instantly to every emergency. NO LUBRICATION.

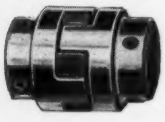
L-R FLEXIBLE COUPLINGS

FREE FROM POWER-WASTING INTERNAL FRICTION



L-R TYPE "WQ"
Pat. & Pats. Pend.
Bores 1¾" to 13¾"

L-R TYPE "WQ"
For wide range of duties, 2.8 to 2350 h.p. Design permits rotation of either shaft for timing of engine or removal of either element, without moving machine or tearing down coupling.



L-R TYPE "IA"
Pat. & Pats. Pend.
Used widely for many services.
½" to 2¼" bores. 1/6 to 50 h.p.

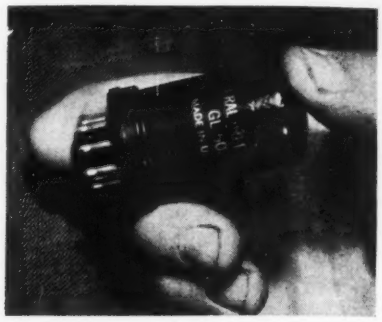
Send for Catalog and FREE Selector Charts

Types and sizes for every service, smallest to largest. Quick-finding charts help you pick just the right coupling for your need. Write

BUY ★ BONDS FOR Victory

LOVEJOY FLEXIBLE COUPLING CO.
5018 West Lake St. **Chicago, Ill.**

wide range. Since grid current is low enough to permit use of a high resistance in the grid circuit, the tube has high sensitivity characteristics. It is relatively unaffected by line-voltage surges as the grid-anode capacitance is



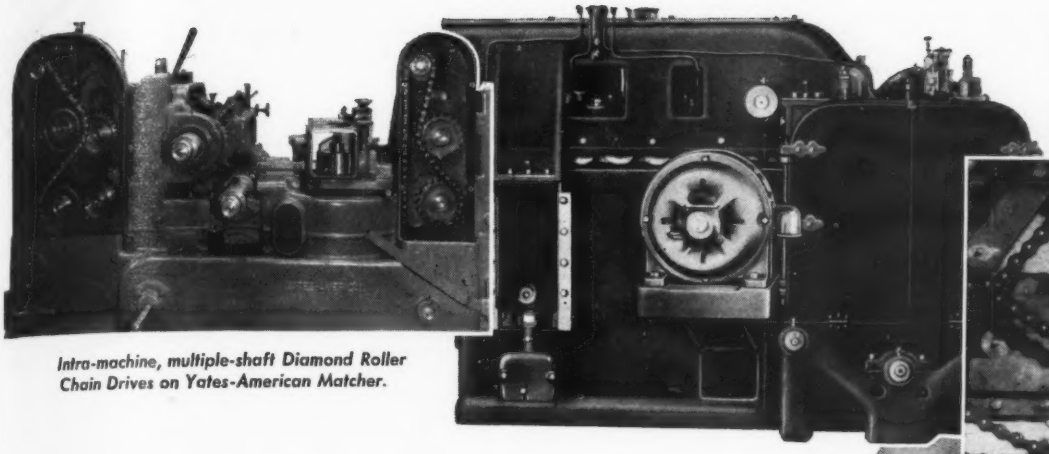
low, and has a maximum peak inverse anode voltage rating of 1300 volts, instantaneous current rating of 500 milliamperes and an average current rating of 100 milliamperes. Cathode is quick-heating and is rated at 6.3 volts, .6 ampere.

Noncritical Redwood Plastic

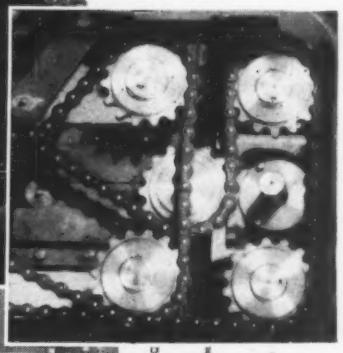
CHEMICALLY perfected from the phlobaphanic structures of the Redwoods, a new noncritical phenolic type thermoplastic is now available in quantities from Pacific Lumber Co., San Francisco. The discovery of this new plastic called Shellerite is shared mutually by The Pacific Lumber Co., The Institute of Paper Chemistry, and Sheller Mfg. Corp., who correlated and financed the research necessary. The new Redwood plastic embodies in one composite form both resin and filler employed in the molding of various parts, and is readily adaptable to either compression molding or the standard equipment of hard rubber plants. Used for various parts previously manufactured from hard rubber and other thermosetting compounds, the plastic has excellent tensile strength with good appearance. When special properties are desired, it can easily be mixed with other resins and plasticizers with absolute control of the formulation ingredients.

Transparent Plastic Tubing

WITH all the flexibility of rubber, a new plastic tubing was recently announced by The Goodyear Tire & Rubber Co., Akron, O. Adapted especially for breweries and creameries, the new transparent tubing is pro-



Intra-machine, multiple-shaft Diamond Roller Chain Drives on Yates-American Matcher.

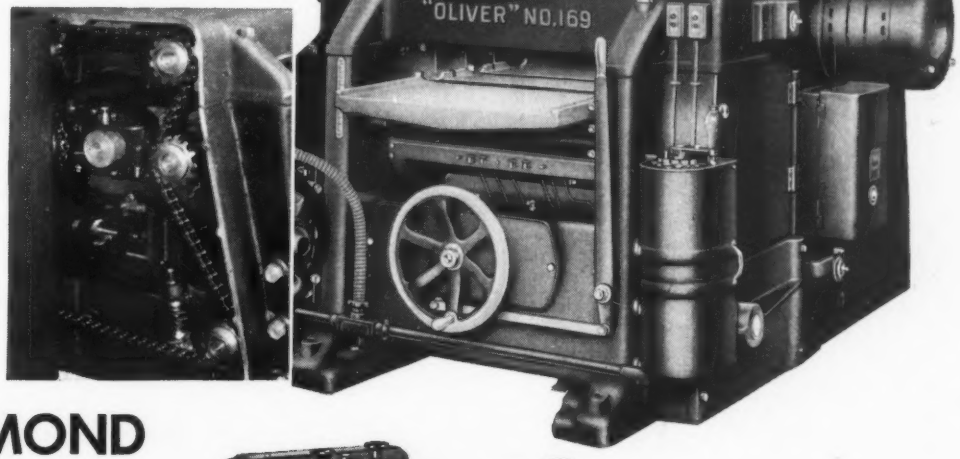


Showing use of Diamond Roller Chains on Straitoplane driving the upper and lower rolls and arranged to compensate for different thicknesses of lumber.

★

LEADERS IN THE WOODWORKING MACHINERY FIELD

Below: *Chain drives of feed rolls on double surfacer.*

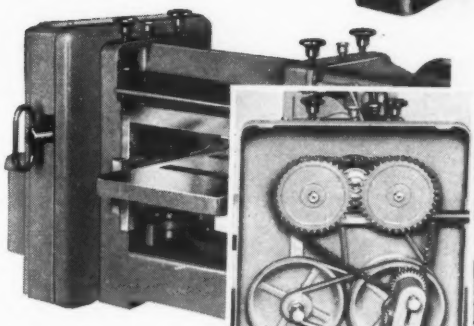


...Select DIAMOND Roller Chains, Too!

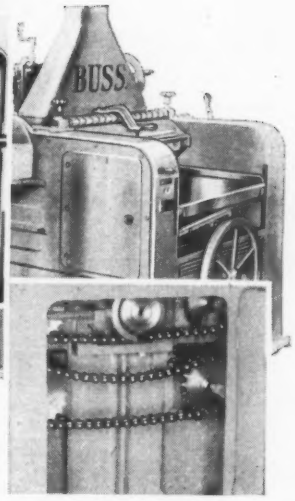
●"User benefit" is foremost in the minds of machinery engineers and designers. Performance in the field is their guide—and this means the performance of all parts,—of which the drives are particularly important.

For a half century makers and users of lumber and woodworking machinery have had first-hand experience with Diamond Roller Chains, have seen the constant improvements and witnessed their constantly enlarging range of usefulness. All these years have proven their great strength, capability of long hour operation, high efficiency—their complete dependability.

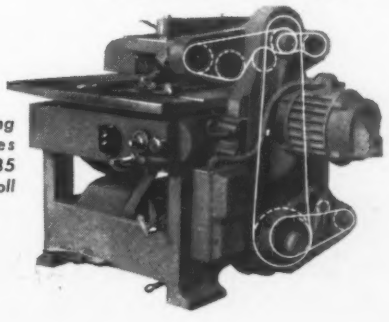
As a result, on leading makes of machinery Diamond Chains always have been used and continue to be used. Long years of preference by machinery users have made Diamond Chains the accepted drives. Their use is good evidence of the machinery builders' integrity. . . . DIAMOND CHAIN & MFG. CO., 435 Kentucky Avenue, Indianapolis, Indiana. Offices and Distributors in All Principal Cities.



Diamond power feed drive on Boice Crane Bench Planer.



Diamond Roller Chains drive top and bottom rolls on Buss Planer.



Hermance Gang Rip Saw uses Diamond No. 435 Chain on feed roll drives.

DIAMOND ROLLER CHAINS

YOU'RE doing a real service helping customers train green hands by equipping your machines with automatic control. Time switches are the best control for certain jobs.

Here's a Good Example

Two G-E time switches control the operation of this oven which bakes meter coils after dipping. All the operator has to do is fill the oven, push the start button, and remove the coils when a lamp lights at the end of the baking period.

One time switch starts the exhauster before the oven heat is turned on—assuring complete ventilation. The other turns on the control circuit for the heater, also turns off the power at the end of the drying period.

Facts about the Time Control

These G-E general-purpose time switches (Type T-44) open and close circuits on a predetermined schedule, with a minimum interval of 45 minutes. They are Telechron motor timed. Contact rating, 35 amp at either 115 or 230 volts. Bulletin GEA-1427 gives full data. Ask your G-E office for a copy, or write General Electric, Schenectady, N. Y.

Interval timer —Send for GEA-1771 | Cyclic timer —Send for GEA-2963 | Vacuum-tube timer —Send for GEA-2902 | Time-delay relay —Send for GES-2616

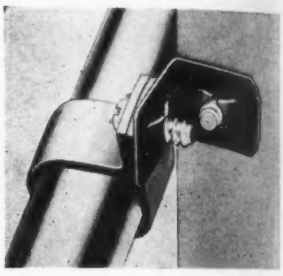
These are but a few of the many G-E timing devices available. If you have a timing problem that these will not solve, ask the G-E office to recommend equipment for your specific need.

Also, ask for our handy chart (GES-2608) that will help you select the right G-E timer for any application.

GENERAL ELECTRIC

duced with materials low on the critical list, thus making it available for a wide range of purposes. The new tubing has practically the same resistance as rubber tubing to extremes of temperature, and will resist pressures up to 40 pounds per square inch when unbraided and up to more than 200 pounds per square inch when braided. In unbraided form the tubing is transparent to disclose immediately any obstructions which might occur. It is also available in an opaque finish or in colors. Tests also disclosed that the plastic tubing in some applications is less prone to pick up odors than rubber tubing. It is produced in the same range of sizes as rubber tubing before the war.

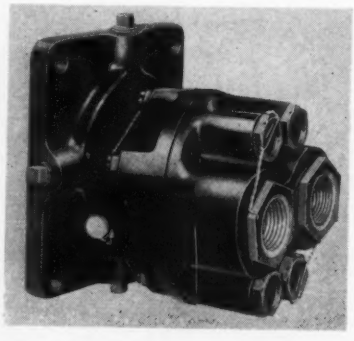
Combination Aircraft Fastener

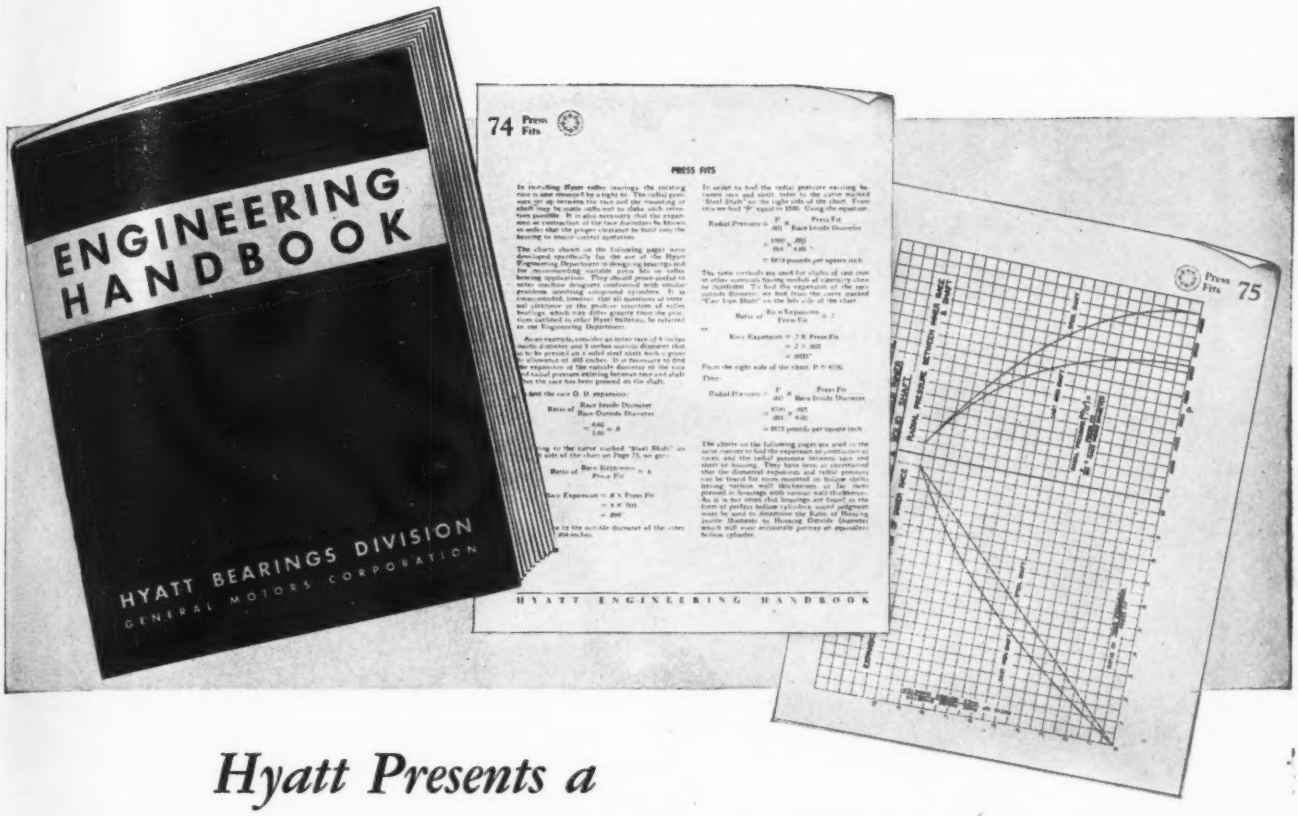


TO COMBINE a bracket and fastening means in a single stamping, a new fastening bracket has been developed by Tinnerman Products Inc., 2085 Fulton road, Cleveland. The new bracket also permits the use of standard bonding clamps in place of ear-type aluminum bonding clamps in the assembly of conduit and piping in aircraft. Prior to the introduction of the fastener, plain brackets were used with aluminum bonding clamps and assembled with separate selflocking units. As an integral part of the bracket, one or more Speed Nuts are formed in this new fastening, which reduces the number of parts and saves weight. Adjustment of conduit or piping at any angle desired is permitted with this combination bracket and fastener.

Hydraulic Pump for Aircraft

TO ENERGIZE systems for operating airplane retractable landing gear, wing flaps, brakes, wing tip floats, turrets, etc., the Pump Engineering Service Corp., 11610 Euclid avenue, Cleveland, has introduced its engine-driven gear-type hydraulic pump. It is available in various models in a range of capacities and various combinations of couplings, mounting flanges and port sizes. Some models are provided with built-in relief valves for controlling discharge pressure. The pump contains two gears mounted in a suitable casing, so arranged that one gear, driven by an external source of power, meshes with and drives the second or idler gear,





Hyatt Presents a

TIME-SAVING, WORK-SAVING SERVICE

for Engineers and Designers of War Products

Just as Hyatt Roller Bearings are helping to speed up Victory in war equipment and in the machines that produce it, now the new Hyatt Engineering Handbook is in the fight.

It's a quick-reference manual... sort of a "scrap book" collection of fundamental engineering data such as you might assemble yourself, from various sources, to obviate the necessity of poring through numerous books to find certain formulae or data.

In addition, it contains much new material which eliminates lengthy calculations. For example, in the 10-page section on Press Fits, charts are used to determine the expansion and contraction of compound cylinders and the radial pressure existing between them. Desired information can be read directly from the charts.

A limited edition of this new 96-page Roller Bearing Engineering Handbook is now being distributed to leading engineers and designers throughout the country. A request on your company letterhead, stating your position, will bring you a copy with our compliments. Hyatt Bearings Division, General Motors Corporation, Harrison, New Jersey

HYATT ROLLER BEARINGS

A DOUBLE CHECK

on the P-51's 1150 hp. Engine

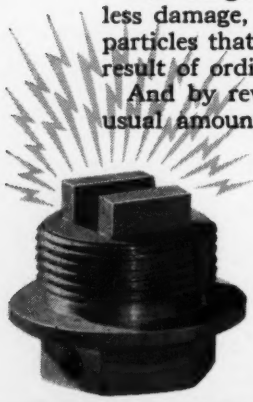
..a check on ENGINE WEAR

..a check on the LUBRICANT

In the oil system of the Allison Engine used in North American's famed P-51, there's a powerful Lisle Magnetic Drain Plug which gives double protection against the hazard of internal engine wear.

The Magnetic Plug protects against needless damage, by removing any ferrous metal particles that may form in the lubricant as a result of ordinary wear.

And by revealing the presence of any unusual amount of abrasive metal, it discloses signs of premature wear long before they would otherwise be discovered.



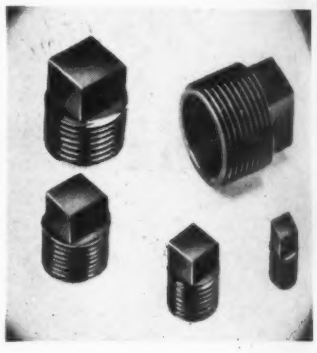
This is only one of many different applications for Magnetic Plugs. Write for data relating to YOUR product.

LISLE CORPORATION
Box 1003, Clarinda, Iowa

Lisle Magnetic DRAIN PLUGS

providing pumping action. Efficiency of pump is determined by clearances between gears and casing. For high pressures these are kept to a minimum. Meshing gears require lubrication which is supplied by fluid handled by pump. For this reason the pumps can handle only fluids such as oil or other viscous liquids which are lubricating in quality and cannot leak back too easily. For continuous operation the pumps handle pressures up to 1000 pounds per square inch, and for intermittent operation handle higher pressures depending on the specific model. Mounted directly on the engine drive, the pump operates as long as engine is running. In the section where the gear teeth disengage as suction is created, the suction causes fluid to be drawn in from adjacent intake port. Then it is carried between the gear teeth to where they engage. Fluid is displaced and forced out through the discharge port into the lines, and directed by valves and flow dividers and controlled by regulators and accumulators, provides the hydraulic power for operating cylinders controlling wing flaps, landing gear, etc.

Plastic Pipe Seal Plugs



NEW plastic pipe seal plugs, according to American Molded Products Co., 1644 North Honore street, Chicago, provide better protection for threads of units in storage or in transit. These light, tough, durable, noncorrosive plastic seals replace critical materials and protect threads against damage, moisture, dirt, weathering, rust and corrosion. While these precision-molded plastic pipe seals are available in five sizes—⅜, ½, ⅝ and ¾-inch—in quantities for quick delivery, other sizes can also be readily supplied upon application.

Hard, Heat-Resisting Finish

RECENTLY developed by the laboratories of Chicago Vitreous Enamel Product Co., Cicero, Ill., a virtually priority-free coating for metal products is aiding materially in the conservation of critical metals. Known as Armor-Vit, it enables manufacturers to substitute steel or iron for critical materials such as brass, copper, stainless steel and aluminum, and can be substituted for such protective coatings as chromium, zinc, tin, cadmium, as well as critical materials in some organic finishes. This finish or coating is a material and a process. While its name suggests a ceramic material there is no connection between it and porcelain enamel, and being inorganic, no comparison with paint, lacquer or synthetic finishes. It is essentially an alkali alumina silicate. Insoluble in water the finish can be sprayed or dipped, and cured in an indirect-fired, air-circulating oven capable of heating to 750 to 800 degrees Fahr. This results in a hard, heat-

Don't touch our original drawings

We PRESERVE them as records only—use PHOTACT prints to take the abuse of frequent handling.

"We've learned our lesson. There was a time when our tracings would become blurry smudges within days after they left the drafting board. If they weren't being man-handled in the office, they were taking a beating in the blueprint room—and turning out mighty poor blueprints at the end.

"But not now. Now, just as soon as a pencil or ink tracing is completed, we make a Photact print of it. Then the original goes into the files for safekeeping as a permanent record.

"Photact ***preserves*** our original, because the Photact print takes the place of that original as the 'master' for reference and reproduction.

"Photact also ***restores*** the old, worn-out drawings. We take one of these limp, over-age drawings—put it through the Photact process—and come out with a new 'master' with lines clearer, opaque and ink-like.

"And, of course, Photact ***duplicates*** our originals. From the negative, we make as many prints as we need—on Photact paper or cloth. They are ideal for government requirements. We also send them to subcontractors and branch plants, because each Photact print can be used for any number of top-quality black-line or blueprints."

* * *

For complete information about the Photact process and Photact papers and cloths, write: Photact Department, KEUFFEL & ESSER CO., Third & Adams Streets, Hoboken, New Jersey.

K+E TRADE MARK

PHOTACT TRADE MARK Reproduction PAPERS AND CLOTHS

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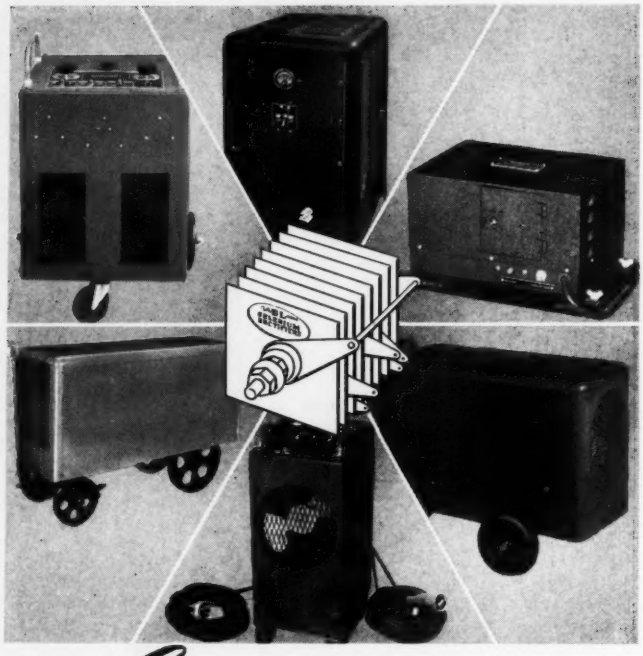


Somewhere in your
POST-WAR PLANNING-
There may be an important place
FOR RECTIFIERS!

BECAUSE of war's demands—and the resultant research and development—the use of dry plate metallic rectifiers has made tremendous advances. Today they are being used for applications once thought impractical; almost impossible.

If your post-war planning includes the use of Direct Current, write us, giving complete details. Our Engineers will gladly study your problem and tell you if modern rectifiers or D. C. power supplies will simplify your design, reduce costs, give more efficient service.

Over twenty-five years' experience in the development, design and manufacture of selenium and copper sulphide rectifier plates and stacks, as well as D. C. power supplies and conversion assemblies, is at your service.

Consult B-L engineers also for recommendations on your immediate problems and needs for war equipment and production.

***AVAILABLE SOON** — A new Data and Specification Catalog of B-L Copper Sulphide and Selenium Rectifier Stacks and Rectifier-Transformer Assemblies (Including Battery Chargers, D.C. Power Supplies, etc.). A copy is yours free as soon as it is ready. Please request it on your company letterhead.*

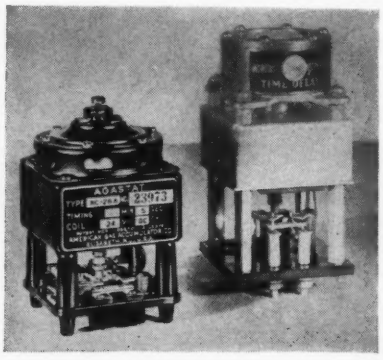
BL
ELECTRICAL
RECTIFIERS

THE BENWOOD LINZE CO., ST. LOUIS, MO.

resisting finish highly resistant to most acids and alkalis. Impact, heat and abrasion are capably endured.

Electropneumatic Time Delay Relay

IN THE redesign of its electropneumatic time delay relay for making or breaking electrical circuits at predetermined intervals, American Gas Accumulator Co., Elizabeth, N. J., gave consideration to increase of operating and functional efficiency, materials available and



reduction in size. By a simple screw adjustment a delay ranging from a fraction of a second to several minutes is obtainable. While the previous model had a minimum of moving parts, the new one has decreased even these to absolute essentials. The basic design and principle have been adhered to. It is a diaphragm type time device, and is unaffected by heat, cold or variations in operating voltage, temperature or humidity. Weight is one pound, 7 ounces; height, 4 inches.

Rough Metal Finish Offered

ANNOUNCED by The Egyptian Lacquer Mfg. Co., 1270 Sixth avenue, New York, is a new wartime rough metal finish called Pebble-Tex for use on parts for military use, instrument panels, fire control and listening devices and other applications where a texture high-speed metal finish is required. Although the

pattern may be obtained with a single application of the finish on the bare metal, it is recommended that it be applied over a primer. The finish is available in a variety of colors and in both the rough and fine textures, and varying degrees in between may be obtained from the same mix by gun adjustment and application technique. The illustration shows a panel with a finer texture finish.

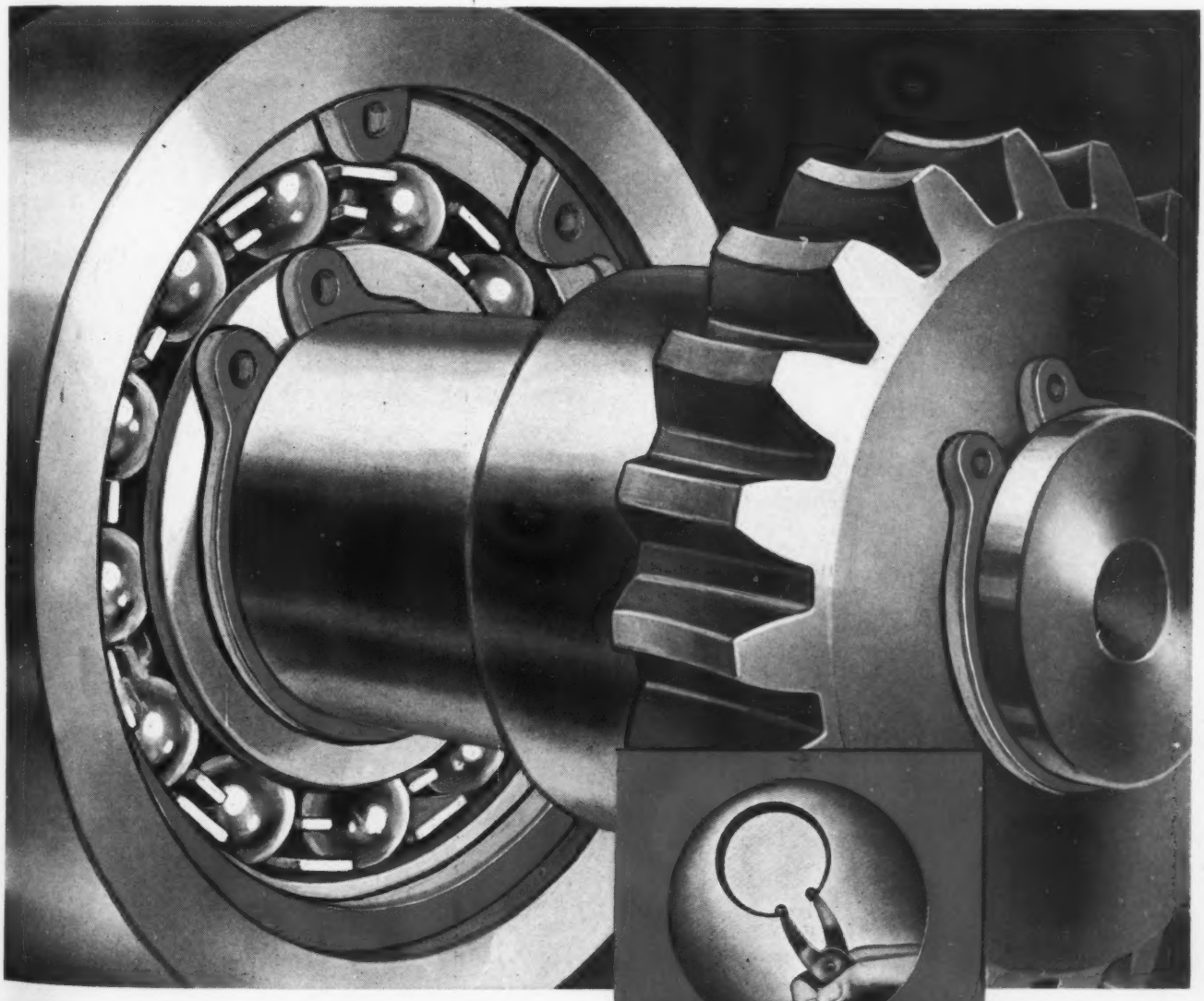
Waldes Truarc presents a significant advance in retaining rings.

It spreads or contracts without distortion; always retaining its perfectly fitting circular contour.

WALDES TRUARC RETAINING RING

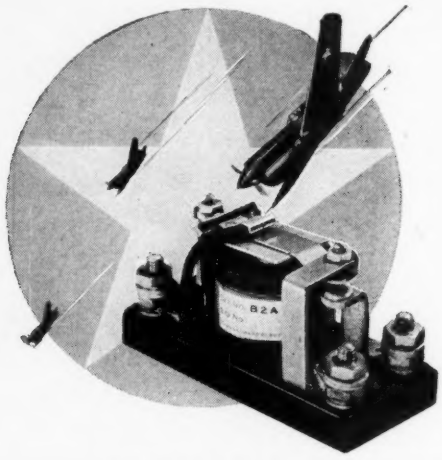
For thrust-load fixing, and shaft and housing applications, Waldes Truarc provides distinct advantages over nuts and bolts or wedges and washers... it reduces dimension and weight... saves material... cuts manufacturing time... simplifies assembly and dis-assembly.

On request, we will gladly furnish samples and full data for your tests.



WALDES KOH-I-NOOR INC ★ LONG ISLAND CITY, N. Y.

BUILT FOR THE AIR SERVICE



W. L. B-2A Relay is rated 25 A. at 25 V. single pole, single throw, normally open contacts

When Ward Leonard developed their B-2A Relay to meet the Army Air Corps tests for vibration and acceleration, they went further than required. They incorporated features in it not found in any other relay.

The layer-wound coils are thoroughly impregnated by a vacuum process that assures better insulation under humid conditions. The tail spring and contact gap are readily adjustable, thus enabling perfect adaptation to the required circuit. The anchorage for the terminal screws molded in the base assures rigidity of the entire relay under vibration.

Yes, this relay is used on aircraft, but the very features that make it desirable for airplane use make it equally desirable for any purpose when a rugged, positive, crisp-acting relay is required. Send for bulletin.

WARD LEONARD

Electric control (WL) devices since 1892.

WARD LEONARD ELECTRIC COMPANY

58 SOUTH ST., MT. VERNON, NEW YORK

MEN OF MACHINES

AT THE recent annual meeting of the American Gear Manufacturers' association, Russell C. Ball was elected president of the organization. He is president of the Philadelphia Gear Works Inc., Philadelphia. Mr. Ball has been active in various activities of the association for a number of years and has served in the capacity of vice president from 1942-1943. To his credit also are chairmanships of numerous committees. His guiding influence in the establishment of the American Gear Manufacturers' association's standards was also of considerable assistance. With reference to his business career, Mr. Ball has been connected with the Philadelphia Gear Works for some time, starting prior to the first World War.

WELL known development engineer, Robert S. Elberty Jr. is now a consultant engineer specializing on design and styling of machinery and electrical drives for automatic operation. A graduate of the University of Cincinnati, Mr. Elberty did some cooperative work while there in connection with the manufacture, design and testing of motors. His first position after graduation was that of development engineer with American Laundry Machinery Co., where he was engaged in research on all new developments, field and laboratory testing laundry and dry cleaning machines, electrical drives and mechanical design calculations. In February 1929 he joined B. A. Wesche Electric Co. as chief engineer and was working on electrical and mechanical design of motors and special machines up to 50 horsepower, magnets, reactors and

... ALL SET, EXCEPT FOR One Part YOU CAN'T GET?

IS progress blocked on your new product . . . is your present war production delayed . . . by one difficult part you can't get? Is it difficult to find equipment to make it fast enough, good enough, to the extreme standards of precision demanded in that part? Should special machinery be designed to make it . . . do you seek a qualified source of supply?

Contact KAYDON

The Kaydon plant is looking for just such problems! Equipped with broad engineering experience and unusual facilities for precision production and technical control, we are qualified to cooperate with your organization in coordinating part design and production methods, to improve use or to speed output. We can make those difficult parts on a high production, low-cost basis, assuring you of the extreme precision, top quality and on-time delivery you demand.

For excellence in production of extremely precise, unusually large ball and roller bearings.

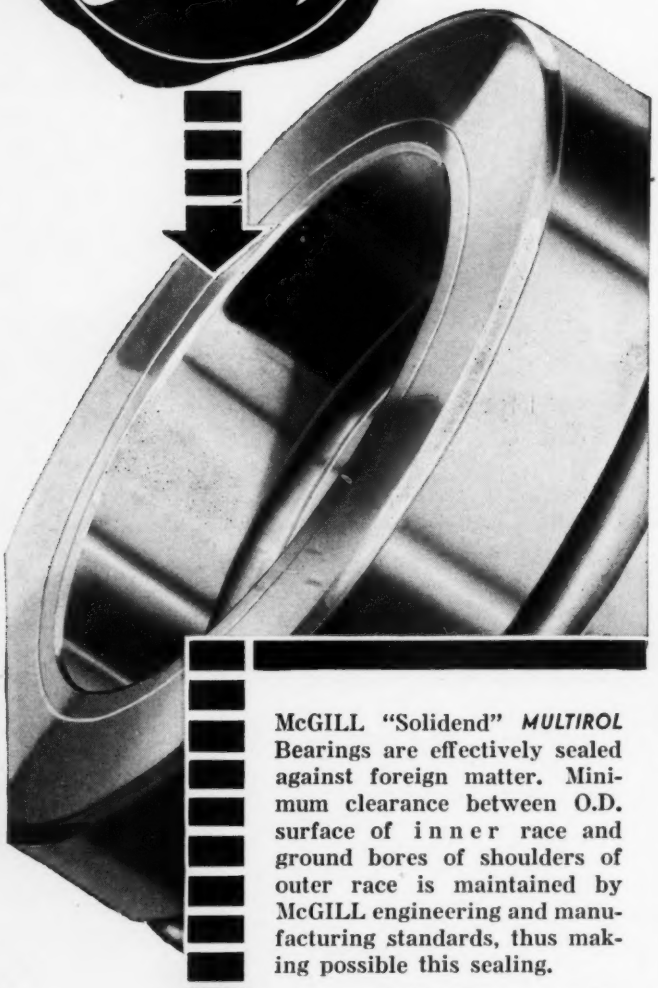
ARMY E NAVY

THE KAYDON ENGINEERING CORP.

McCRACKEN STREET • MUSKEGON, MICH.

Specialists in Difficult Manufacturing

EFFECTIVE *Sealing*



McGILL "Solidend" *MULTIROL* Bearings are effectively sealed against foreign matter. Minimum clearance between O.D. surface of inner race and ground bores of shoulders of outer race is maintained by McGILL engineering and manufacturing standards, thus making possible this sealing.

This small clearance so effectively seals in the lubricant that, in many cases, no auxiliary seal of felt or metal is necessary.

Use your Priority in order to secure McGILL "Solidend" Bearing Superiority.

BEARING DIVISION
1450 N. Lafayette St.

McGILL Manufacturing Co., Inc.,
Valparaiso, Indiana

torque motors. In November of that year he became industrial application engineer at Westinghouse, devoting his time to the development and application of electrical equipment for laundry machines, machine tools, valves and special machines. After five years Mr. Elberty began to do machinery electrification sales work for the company and handled relations with industries using electrical equipment. He conceived and managed the first two Machine Tool Electrification Forums, now sponsored annually by the company. From September 1937 to April 1942 he was electrical and assistant chief engineer for Landis Tool Co., working on new developments and research; electric, mechanical and hydraulic drives; styling; and sales engineering. From there he went to the T. W. & C. B. Sheridan Co. as experimental engineer where he remained until early this year. In this position he assisted the president with conversion to war work and new developments. Mr. Elberty has fourteen patents, and is well known to readers of MACHINE DESIGN through articles he has contributed to this journal.

°

NEWLY elected president of the American Society of Tool Engineers for 1943-44 is Ray H. Morris who is vice president of Hardinge Bros. Inc., West Hartford, Conn. Mr. Morris was born in Turners Falls, Mass. Apprenticed as a machinist in several plants in Springfield, Mass., he joined Pratt & Whitney in 1916. Four years later he became sales and service engineer for the Pratt & Whitney company and was located in various cities during the next twelve years. In 1932 he joined Hardinge Bros. Inc., of which he is now vice president. Mr. Morris also has been chairman of the Hartford Chapter of the American Society of Tool Engineers in 1940.

°

R. M. ELLIS has joined Aircraft Parts Development Corp., Summit, N. J., as chief mechanical engineer. He has a background of twenty years in research and design, gained through his connections with Brewer Titchener Corp., Remington Rand Inc., Pathe Film Corp., and Conmar Products Corp.

°

H. B. HARVEY, president, Harvey Metal Corp., has been elected president of the Brass Forging association. FRED RIGGIN, president, Mueller Brass Co., has been made vice president of the association.

°

J. H. COOPER has been given an indefinite leave of absence by Taylor-Winfield Corp., Warren, O., with which he has been associated the last six years as welding engi-

In recognition of their "patriotism and great work," Emerson-Electric workers were presented with the Army-Navy "E" Award.
Now...
Teamed for Victory
Today—and as long as the war lasts—Emerson-Electric's entire output of precision-built electric motors is teamed with United Nations' aircraft, battling on the air fronts of the world.
Teamed for Service
There are scores of standard uses for high quality, standard motors. Emerson supplies them every day—has for years.
But with the rapid development of new motor-driv
vices and appliances there is a never-ending dema
individual engineering service—for specially de
motors to fit specific needs. These needs frequently
a mere hair's breadth difference—a difference, h
that makes a champion instead of a runner-up.
It is in this field of individual engineering ser
Emerson has won its leadership in the motor in
cause with ceaseless research, specially designed
equipment, and veteran, advanced-thinking
Emerson has become capable of supplying tha
difference between standard and individuali
motors.
Find out how Emerson's individual engine
can solve your motor problems. Write for B
TODAY.
EMERSO
MOTO
3 HP and smaller—Single-phase—Polypho
THE EMERSON ELECTRI
ST. LOUIS
NEW YORK
LEADERS IN THE FAN AND MOTOR INDUSTR
SO THAT THE WORLD MAY READ
PAGES FROM AVIATION'S HISTORY
MISSION ACCOMPLISHED
Hit true—hit hard—get away fast! That's all there is to a successful bombing expedition. But—it takes split-second co-ordination of a finely trained crew and precision-built equipment, to produce such results. Emerson-Electric Aircraft Motors that drive gun turrets, operate fuel pumps, tab controls, and do many other vital jobs—instantly and unfailingly—are helping United Nations Flyers all over the fighting world, return and report..."Mission Accomplished!"
THE EMERSON ELECTRIC MANUFACTURING CO.
ST. LOUIS... Branches: New York • Detroit • Chicago • Los Angeles • Davenport
LIGHTWEIGHT, COMPACT, POWERFUL—Emerson-Electric Aircraft Motors are made for gun-turret drives, hydraulic units, fuel pumps, tab controls, winterizing, commencing systems, also with built-in gear and limit stop.
EMERSON ELECTRIC
MOTORS • FANS • APPLIANCES • A. C. ARC WELDERS

A PAGE FROM A FORMER YEAR

In times of peace, Emerson-Electric motors were teamed perfectly with scores of nationally-known products for civilian use... as they will be again when this war is won.

Electric Aircraft Motors for gun-turret drives, hydraulic units, cowal flap controls and RADAR control equipment, are just a few of the many war products now flowing from Emerson-Electric production lines. Out of the rich experience thus gained have been developed many design improvements, increased efficiencies and greater operating economies—factors vitally important in the plans of manufacturers who will supply the motor-operated appliances and equipment of the post-victory world.

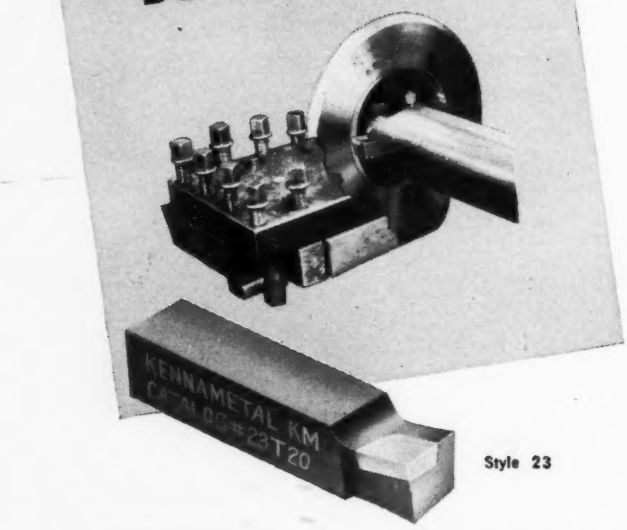
THE EMERSON ELECTRIC MFG. CO.
SAINT LOUIS... *Branches:* New York • Detroit
Chicago • Los Angeles • Davenport

A page from Emerson-Electric's current aircraft motor advertising

EMERSON ELECTRIC
MOTORS • FANS • APPLIANCES • A. C. ARC WELDERS

7 Reasons

FOR USING KENNAMETAL* SINGLE POINT BORING TOOLS



Style 23

1. A single point *Kennametal* boring tool cuts steel at three to six times the RPM possible with a multiple-blade cutter of tool steel.
2. A single point *Kennametal* tool permits the use of a piloted boring bar on long bores.
3. The single point *Kennametal* tool with a small nose radius reduces tendency to chatter caused by tool pressure.
4. A single point *Kennametal* tool, in an ordinary boring bar, can be positioned more easily, adjusted for size readily.
5. The single point *Kennametal* tool can be ground off-hand—the multiple-blade type must be ground in a cutter grinder.
6. The single point *Kennametal* tool holds a truer bore, is less likely to "follow" an off-center hole.
7. The single point *Kennametal* tool costs much less than a two-blade boring cutter.

Write for your copy of Catalog 43B which gives information about tools for specific boring operations.

KENNAMETAL THE All American CARBIDE

*INVENTED AND MANUFACTURED IN U. S. A.

McKENNA METALS Co.
146 LLOYD AVE., LATROBE, PA.
Foreign Sales: U. S. STEEL EXPORT CO., 30 Church St., New York
Exclusive of Canada and Great Britain

neer, to act as chief, Resistance Welding section, General Industrial Equipment division, War Production board, Washington.

J. M. LUTHER has taken the post of assistant chief engineer at Globe Aircraft Co., Fort Worth, Tex. He previously was connected with Curtiss-Wright.

C. A. THAYER, formerly chief engineer, Republic Steel Corp., Cleveland, has been appointed consulting engineer. R. H. BAHNEY, formerly assistant chief engineer, becomes chief engineer.

JOHN W. VOTYPKA has been appointed head of the Production Service and Smaller War Plants divisions of the Detroit regional office of WPB. He has been associated with the automotive industry since 1913 when he started working for Fisher Body Co. Before his present appointment he was director of engineering for Fruehauf Trailer Co.

A. W. HERRINGTON, SAE past president and recently elected a director of the Army Ordnance association, was principal speaker at the annual alumni meeting of the Stevens Institute of Technology.

JAY A. BOLT has joined the Stromberg Aircraft Carburetor section, Bendix Products division, South Bend, Ind., as project engineer. Prior to his new connection he was assistant professor of the department of aeronautical engineering, University of Notre Dame, Indiana.

CHARLES P. SANDER has accepted a position in the engineering department of Ranger Aircraft Engine division of Fairchild Engine & Airplane Corp., Farmingdale, L. I., N. Y. He formerly had been chief engineer of Kinner Motors Inc.

JACKSON G. KUHN, who has been assistant engineer of Kinner Motors Inc., Glendale, Calif., has been promoted to chief engineer. GUNNAR EDENQUIST has been elected vice president and assistant general manager of the company.

R. E. ZIMMERMAN has been re-elected president of the American Standards association. He is vice president of the U. S. Steel Corp., Pittsburgh.

FRANCIS T. MCNAMARA, associate professor of electrical engineering at Yale university since 1923, has been made deputy director of the Communications Equipment division of the War Production board.

HERBERT R. PASS has left his position as assistant aeronautical engineer, National Advisory Committee for Aeronautics, Langley Field, Hampton, Va. He is now senior aero dynamicist at the Hughes Aircraft Co., Culver City, Calif.

THE "COPPER BAR" CASE

—and how Hele-Shaw Fluid Power Engineers Solved it

In a certain copper refinery, whose name you would instantly recognize, they were having trouble. Continuous pouring of copper bars was yielding more than an allowable percentage of rejects. The guilt was traced to an electrical device tilting the ladle. The device, it was found, was jerking and jarring the ladle and shimmying the flow of metal.

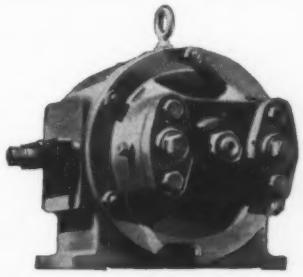
They had a hunch Fluid Power could help them, so they called in our engineers.

Hele-Shaw engineers studied the "case" and recommended a hydraulically operated lift for the ladle, powered by a special hand-lever controlled reversible Hele-Shaw pump. That was in 1935. Thereafter, the ladle tilted and poured with the satin smoothness characteristic of Fluid Power. The device and the Hele-Shaw pump have been on duty ever since. Other metal refineries, in fact, eagerly duplicated it.

Yours may be an entirely different reason for looking into Fluid Power—but with equal opportunities for success. If you have a notion Fluid Power may improve a product or process, or simplify the control or operation of a machine in your post war planning, ask Hele-Shaw engineers to tackle the job.

THE **Hele-Shaw** *Fluid Power Pump*

Æ CO 75th ANNIVERSARY



OTHER A-E-CO PRODUCTS: TAYLOR STOKERS, MARINE DECK AUXILIARIES, LO-HED HOISTS

AMERICAN ENGINEERING COMPANY

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I-S
BERYLLIUM
COPPER
BRUSH SPRINGS
Reduced loss of tension with brush wear.
Safe at 300 deg. F.
28% conductivity.
Closer tolerances eliminate need for necked down ends.
No set or drift.
GET THE FACTS
on how these advantages are obtained—plus hand book data for designing "Micro-processed" beryllium copper brush springs in I-S Bulletin No. 5. Write for your copy.
BETTER BRUSH SPRINGS

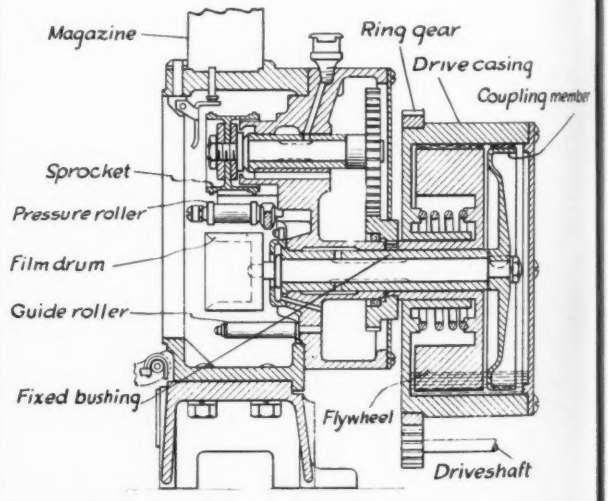
Specialization telescopes time. Instrument Specialties Company has perfected beryllium copper brush spring design and production by the development of "Micro - Processing" — the only method by which all of the physical and electrical properties of beryllium copper are successfully controlled to meet the individual requirements of every order regardless of quantity.

INSTRUMENT SPECIALTIES COMPANY
DEPT. C LITTLE FALLS, NEW JERSEY

NOTEWORTHY PATENTS

Saves Film in Sound Recorder

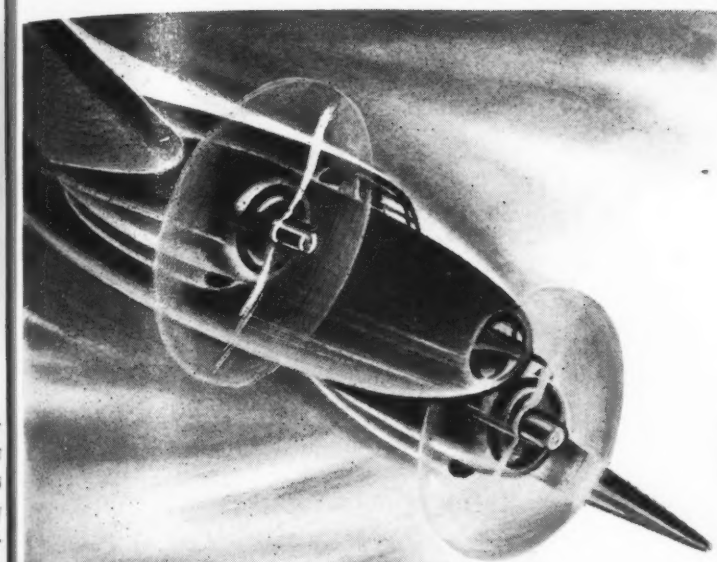
SOUND-FILM driving mechanisms must maintain extremely uniform film velocity past the recording or reproducing point. In apparatus covered by previous patents the average speed of the film is determined by a positively driven sprocket while the necessary uniformity of motion is assured by passing the film over a drum driven through a yielding connection which permits no transmission of vibration. With mechanisms hitherto employed the positively driven sprocket on starting attained full speed much more rapidly than the yieldably driven film drum, occasioning the loss of an appreciable amount of film before recording could begin. This objection is overcome in a design covered by patent 2,304,392, recently assigned to the Radio Corp. of America.



Sprocket and film drum are rapidly brought up to full speed without residual oscillation in the drive

Film from the magazine passes downward around the sprocket and film drum (see accompanying figure) then back to the magazine, being guided by the idler roller and maintained in contact with the film drum by the pressure roller. Power is supplied through the motor driveshaft and pinion which drive the ring gear on the outside of the drive casing. The casing is made massive in order to stabilize the drive.

Drive casing is partially filled with viscous liquid which transmits rotation to the film drum through the coupling member which fits with small clearance inside the casing. Also contained in the drive casing is a flywheel connected through a pinion and gear to the sprocket. The flywheel rotates on the outside of the fixed bushing and is coupled to the drive casing through a torsional spring



GEARS
TO BLITZ THE AXIS

TODAY . . . Perkins Precision, Custom Cut Gears are helping to blitz the Axis on every fighting front. Aircraft engine gears, supercharger worms, parts for gun mounts, gear reducing units and many other precision parts needed by our armed forces leave the vastly enlarged Perkins plant in a never-ending stream and will continue to do so until Victory.

TOMORROW . . . When peace returns, Perkins gears will also return from the fighting fronts to resume their place in thousands of civilian products—doing again the jobs that only precision, custom-cut gears can do with fullest effectiveness and greatest satisfaction to the ultimate consumer.

This Company's technical staff is at industry's disposal for the solution of any problem involving the design and mass-manufacture of precision gears for pre-determined purposes.

PERKINS MAKES:

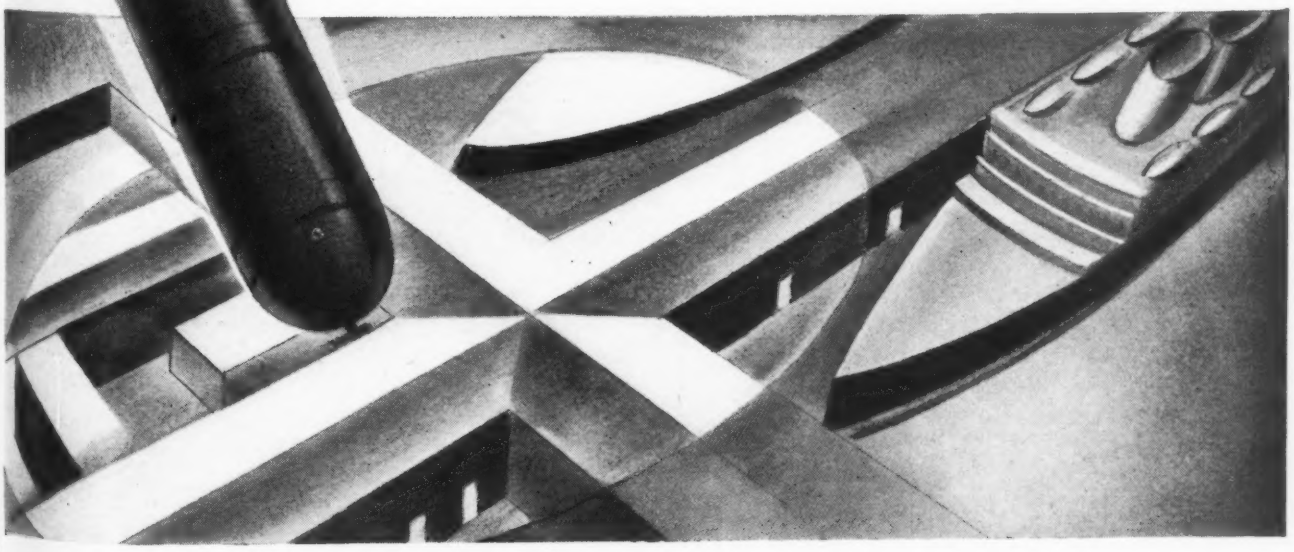
HELICAL GEARS BEVEL GEARS RATCHETS
WORM GEARS SPIRAL GEARS SPUR GEARS
GROUND THREAD WORMS

Consult with our Engineering Staff!

PERKINS PRECISION, CUSTOM-CUT GEARS

help power American Planes, Tanks and Guns

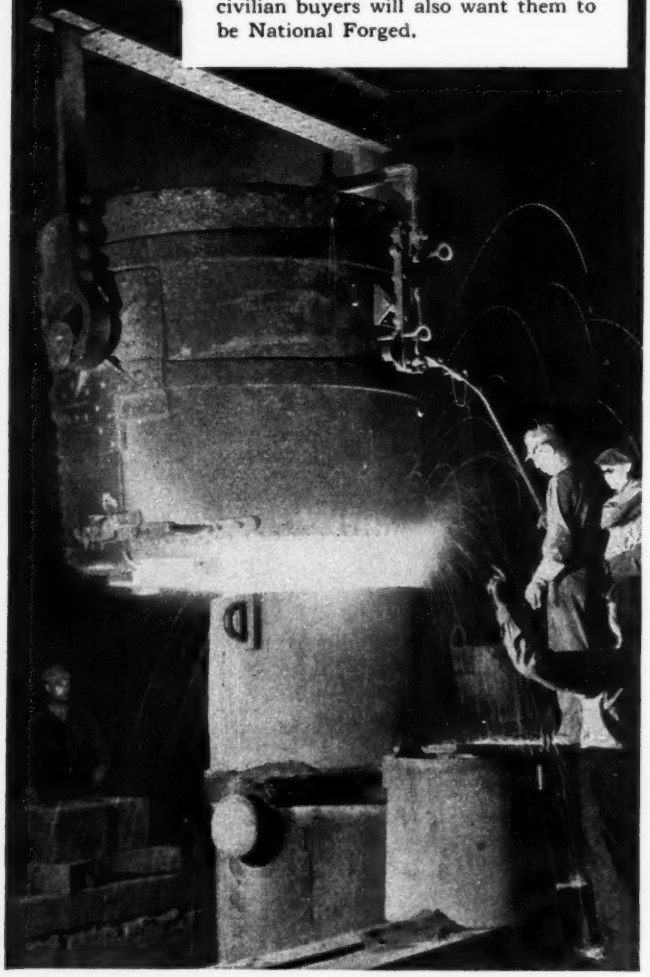
PERKINS MACHINE & GEAR COMPANY, SPRINGFIELD, MASS.



QUALITY IS ONE DIVIDEND THIS WAR WILL PAY

America is not content merely to give its fighting men more and more fighting tools. For those tools must be the finest fighting equipment ever made—and they are!

That means finer steel, better metallurgy, more skillful forging, improved heat treating, and machining of surpassing skill and precision. In fully meeting such exacting wartime standards, National Forge also prepares for the quality markets that peace eventually will bring. When heavy duty steel forgings are again needed by industry, civilian buyers will also want them to be National Forged.



NATIONAL FORGE & ORDNANCE CO.

IRVINE, WARREN COUNTY, PENNA.

"WE MAKE OUR OWN STEEL"

For Excellence in Production

Awarded for sustained excellence April 24, 1942

Second Star Awarded for Continued excellence Oct. 24, 1942

and also through the viscous action of the liquid in the casing. Spring assures a synchronous drive to the sprocket while the viscous fluid provides sufficient damping to prevent periodic oscillation.

When the driving mechanism is started the coupling member due to its lightness is rapidly brought up to speed although the more slowly accelerating flywheel tends to retard it slightly. As the flywheel accelerates more slowly than the drive casing the spring is placed under considerable torque and the stored energy later released brings the flywheel speed slightly above normal, assisting in the acceleration of the drum. However, as soon as the flywheel exceeds the speed of the driving member the viscous fluid within the drive casing tends to retard the flywheel and to bring it back to the proper speed while at the same time damping any tendency toward oscillation. In consequence the sprocket and drum are promptly brought to normal running speed without periodic oscillation.

Because of the nature of the sprocket drive irregularities in the motion of the driver are prevented from reaching the sprocket. At the same time any irregularity imparted to the film by the mutual action of the sprocket teeth and the sprocket hole spacing in the film is effectively eliminated by the filtering action of the fluid drive to the film drum.

Pneumatic Pressure Operates Aircraft Pump

FOR high altitude aircraft, provision of a booster pump at the fuel tanks overcomes resistance of long fuel lines and inhibits vapor lock. One of the problems in installing a fuel pump at the tank outlet is the furnishing of power and control equipment that will not be unduly heavy. A pneumatic booster pump which may be energized either by a light air pressure line running from a small engine-driven air compressor or preferably from the pressure side of the engine supercharger is covered by patent 2,307,566, assigned to the Wright Aeronautical Corp. Objectives of the design include delivery pressure substantially proportional to the pressure available for operating it, delivery flow only as great as the demand for fuel, minimum agitation of the fuel, minimum pulsation in delivery, and snap action valve control.

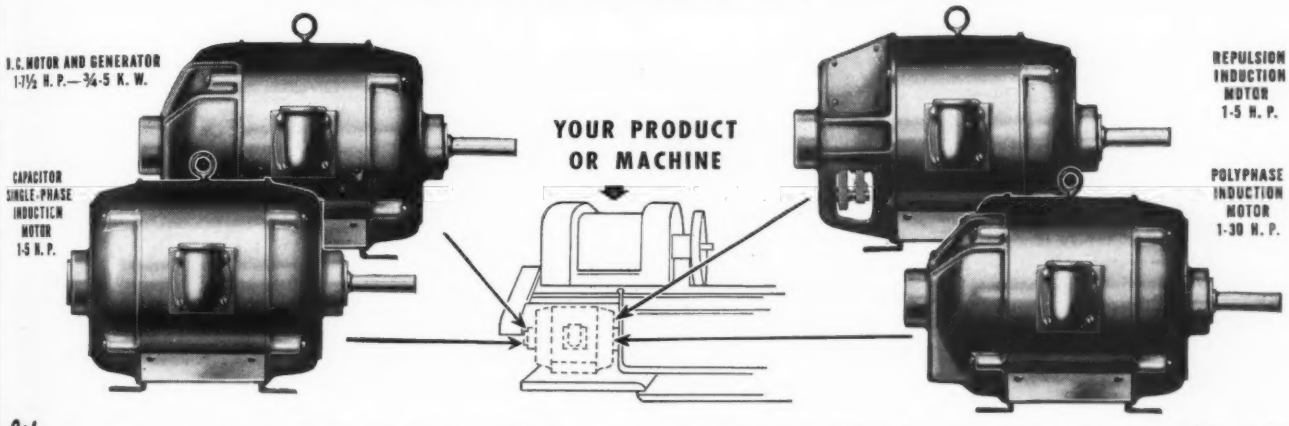
Employs Flexible Diaphragms

As the figure shows, the pump consists of a central body portion comprising cupped circular plates between which are the fuel intake and discharge passages, separated by an integral wall. Attached to the right-hand plate is an auxiliary housing, the intervening space forming a pump chamber which is divided by a flexible diaphragm into a motor compartment to right and a fuel compartment to left of the diaphragm. The diaphragm is held at its outer edge between the body and the housing, the center being gripped between two metal disks secured to the end of a reciprocating sleeve. To the left of the body is a similar pump chamber enclosed on the outside by the valve housing. A diaphragm separates this space into a motor compartment, left, and a fuel compartment, right.

Sliding inside the reciprocating sleeve is a hollow valve

Look! You can INTERCHANGE *R&M Uni-Shell* MOTORS INSTANTLY!

They're the only complete motor line in which all types in any one frame size are interchangeable and similar in appearance!

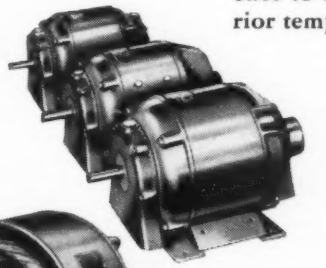

D.C. MOTOR AND GENERATOR
1-1½ H. P.—¾-5 K. W.
CAPACITOR SINGLE-PHASE INDUCTION MOTOR 1-5 H. P.
YOUR PRODUCT OR MACHINE
REPULSION INDUCTION MOTOR 1-5 H. P.
POLYPHASE INDUCTION MOTOR 1-30 H. P.

Whether you manufacture motor-driven products or just use motors on the production machines in your shop, you can readily see the tremendous advantage that R & M Uni-Shell Motors offer you in *complete interchangeability.* No longer need you redesign or rebuild machines to take different types of motors, for where one type of Uni-Shell Motor can be mounted, so can *any* in the same frame size! Shell dimensions, shaft-head fit, bolt circle holes, base, shaft size and conduit box mountings are identical for all.

In the 30-month development and testing period R & M engineers worked out many *other* improvements, too, that make Uni-Shell Motors the most efficient, dependable and durable in R & M's 50 years of motor building. For complete protection, they're built in shells of steel. Better bearings and better balancing assure unusually smooth, trouble-free operation. New insulating techniques, together with the finest materials obtainable, increase motor life. And we have utilized our broad fan-building experience to make ventilation better than ever, keeping interior temperatures *below* guaranteed maximums.

DRIP-PROOF, SPLASH-PROOF MOTORS

have covers added, or special heads. Left to right: polyphase, direct current, and repulsion induction motors with covers.



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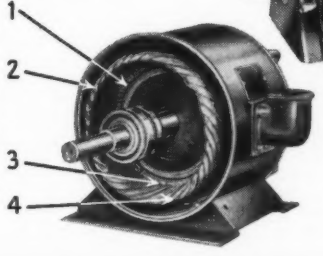
1. Two layers of highest-grade impregnated rag paper. 2. Wire coated with double-weight synthetic resin for strength and flexibility. 3. Added sheet of impregnated paper placed between coils in slot. Improved method used for holding end coils. 4. Entire winding assembly given several baked coats of synthetic resin-base varnish and covered with moisture-resistant synthetic resin and tung-oil sealer.



20-PAGE BOOKLET TELLS THE WHOLE STORY

All of the many advantages and features of R & M Uni-Shell Motors are fully described and illustrated in a 20-page booklet just off the press. To get *yours* promptly, fill in the coupon below and mail it today.

Mail This Coupon Today!

ROBBINS & MYERS, INC., Springfield, Ohio

Gentlemen: Please send me your new 20-page booklet on Uni-Shell Motors.

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I would ☐ would not ☐ like to talk to a representative. MD3

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HOISTS & CRANES • MACHINE DRIVES • FANS • MOYNO PUMPS • FOUNDED 1878

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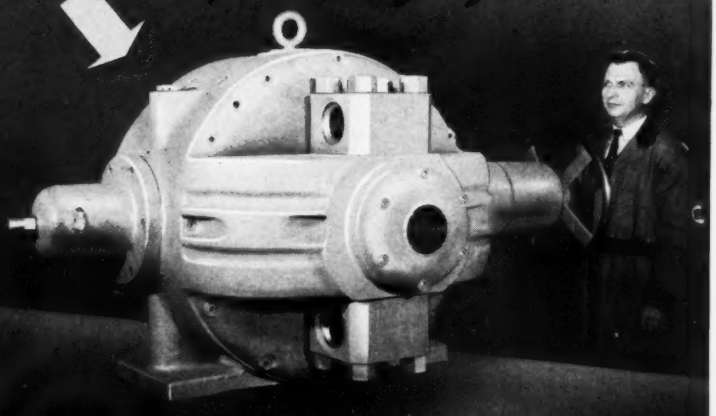
HYDRO·POWER
RADIAL PUMP
For Every Hydraulic Pressure
Generating Application
Regardless of size



All reciprocating actions requiring heavy forces can be powered hydraulically to advantage by employing variable, reversible delivery characteristics of the HYDRO-POWER Radial Pump. Dependable operation is always provided through exclusive HYDRO-POWER design, including the ultra precision Tapered Roller Bearing mounting of cylinder rotor on the valve spindle. Positive maintenance of original close operating clearance is guaranteed; freedom from rotor friction is assured. This "split hair" accuracy is maintained for pump life by an occasional simple adjustment outside the pump. Detailed information on these HYDRO-POWER PUMPS sent upon request.

HYDRO-POWER SYSTEMS, INC.
Division of The Hydraulic Press Mfg. Co.
Mount Gilead, Ohio, U. S. A.

LARGE RANGE OF CAPACITIES

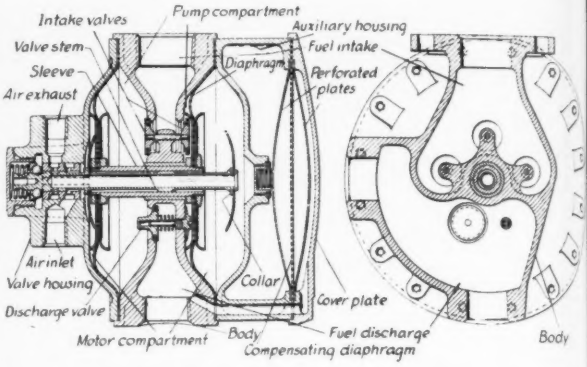
Model and Size	G-P-M
R-2	1-1/4
R-10	5
R-25	11
R-50	23
R-100	50
R-200	95
R-400	185

Pressure ratings up to 2500 pounds per square inch

hydro power

HYDRO·POWER
HYDRAULIC PUMPS AND CONTROLS - VALVES - CYLINDER AND RAM ASSEMBLIES - POWER UNITS - SYSTEMS - SPECIAL HYDRAULIC EQUIPMENT.

stem carrying at its left-hand end a piston valve for controlling the admission and release of air for operating the pump. With the sleeve and diaphragms in the position shown in the figure, air entering the inlet flows through the ports surrounding the valve and into the compartment to the left of the left-hand diaphragm. Air pressure on the diaphragm pushes it to the right, carrying with it the sleeve and the right-hand diaphragm. Air in the space to the right of the right-hand diaphragm exhausts through the hollow stem of the valve to the exhaust port. During this movement fuel is drawn through the intake valve



Double-acting diaphragm pump includes snap-action control and pulsation compensator

into the compartment to the left of the right-hand diaphragm, while the fuel in the compartment to the right of the left-hand diaphragm is delivered through the discharge valve.

Near the end of the stroke the sleeve makes contact with a collar on the end of the valve stem and for the remainder of the stroke carries the valve with it until the valve reaches the limit of its travel. The air inlet now communicates with the right-hand side of the right-hand diaphragm while the left side of the left-hand diaphragm is opened to the exhaust through holes drilled in the valve housing surrounding the valve, which carry the air into the space to the left of the valve. The sleeve and diaphragms now move to the left, giving another pumping stroke, until the valve is once more shifted and the cycle repeats.

Spring Detent Positively Locates Valve

Snap action is obtained through the use of two annular grooves to the left of the valve, working in conjunction with a series of small balls abutting the end of the valve liner and held in place by a spring and chamfered washer. When axial pressure on the valve stem becomes sufficient to spring the balls out of whichever groove they happen to be in, the stem shifts into its new position. Any possibility of the valve becoming stuck in the mid-position is avoided through the action of spring fingers on the ends of the reciprocating sleeve, which engage the diaphragm plates prior to the contact of the sleeve and collar. The small amount of potential energy stored in the spring fingers is sufficient to speed the sleeve on its way as soon as the balls are released from their groove.

Substantially constant delivery of fuel is secured by the compensating device incorporated in the auxiliary hous-

NO GADGETS, NO WIDGETS OR TRINKETS!

We are neither equipped nor interested in producing dime store wares, but if you are looking for an organization to design, engineer and build machines or equipment, you will want to investigate our facilities.

We offer:

Undivided Responsibility for all phases of production metal working, fabricating, machining, finishing and assembly, all under one roof — including purchasing and expediting delivery of motors, clutches and other assemblies.

Central Location near the geographical heart of the nation. Excellent shipping facilities. Equi-distant to markets and sources of supply.

Skilled Labor to insure quality workmanship and deliveries on schedule.

Sound Engineering by a staff capable of designing a machine, engineering changes on existing machines and competent to handle production.

We invite your inquiry by letter, phone or wire.

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ELECTRODES
that produce
TOUGH METAL
for the
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AGILE Silver Series
WELDING ELECTRODES
These electrodes produce a weld metal with the following qualities—EXTREME TOUGHNESS, MAXIMUM SHOCK RESISTANCE and LONG LIFE FOR CUTTING EDGES. They are the last word for repairing or building heavy duty forming dies, chisels, shear and chopping blades, concrete beaters, lathe and planer cutting tools, etc. Ordinary welding technique is all that's necessary for their application. AGILE SILVER SERIES electrodes put the "possible" in "impossible."
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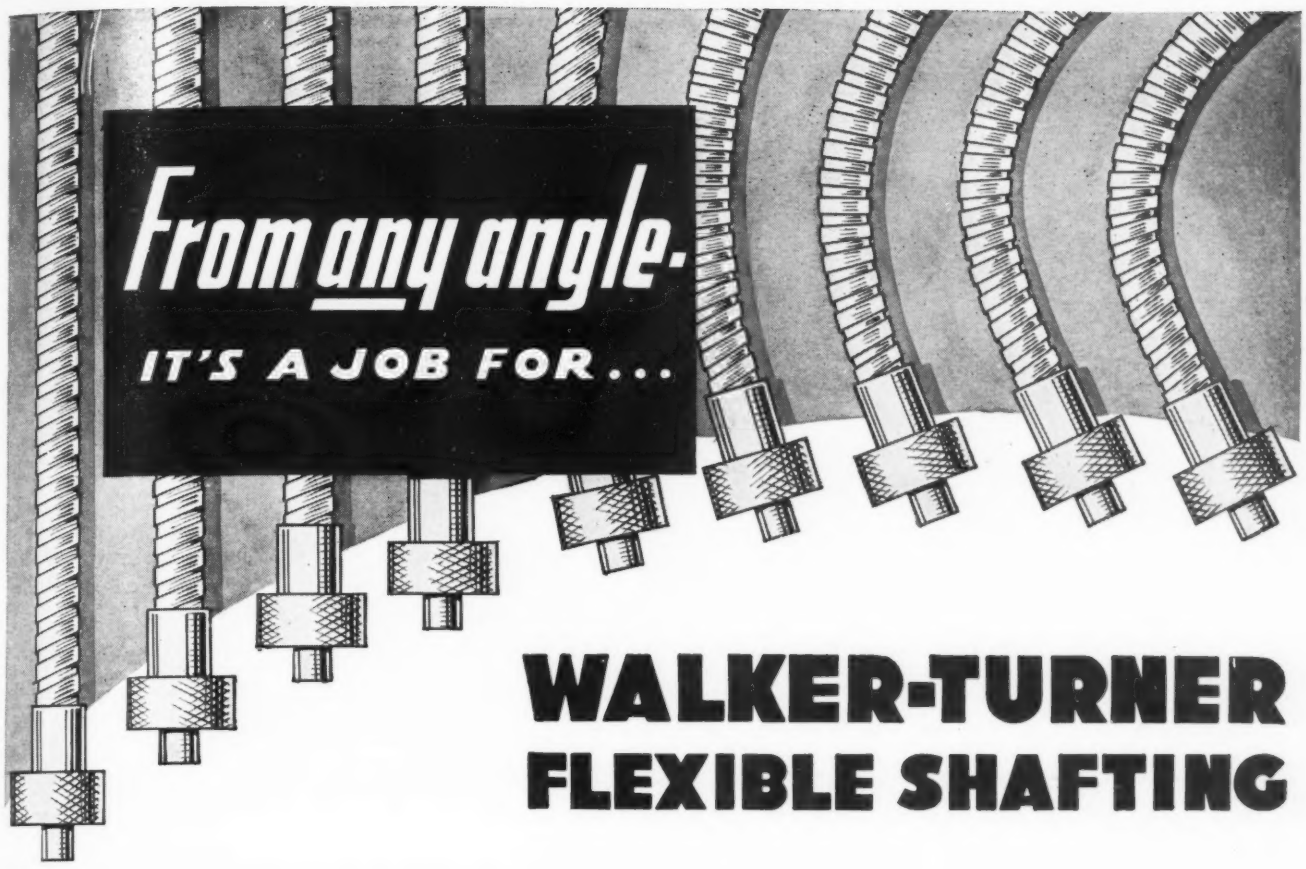
ing. This consists of a compensating diaphragm supported at its edge between the auxiliary housing and the cover plate. Deflection of the diaphragm due to pressure on either side is limited by a pair of perforated cup-shaped plates. Right-hand side of the diaphragm communicates with the fuel discharge passage. Left-hand side is under pressure slightly less than that of the air supply due to its connection with the adjacent motor compartment through a spring-loaded valve provided with a small bleed orifice. When the motor compartment is under pressure the valve opens, admitting air to the space to the left of the diaphragm, and when it is exhausting a small amount of air bleeds back through the orifice. While the pump is discharging fuel, the compensating diaphragm deflects to the left, allowing fuel to store up behind it. When the pump stops at the end of each stroke and discharge ceases momentarily, pressure to the left of the compensating diaphragm drives it to the right, discharging the fuel which has accumulated during the pumping stroke.

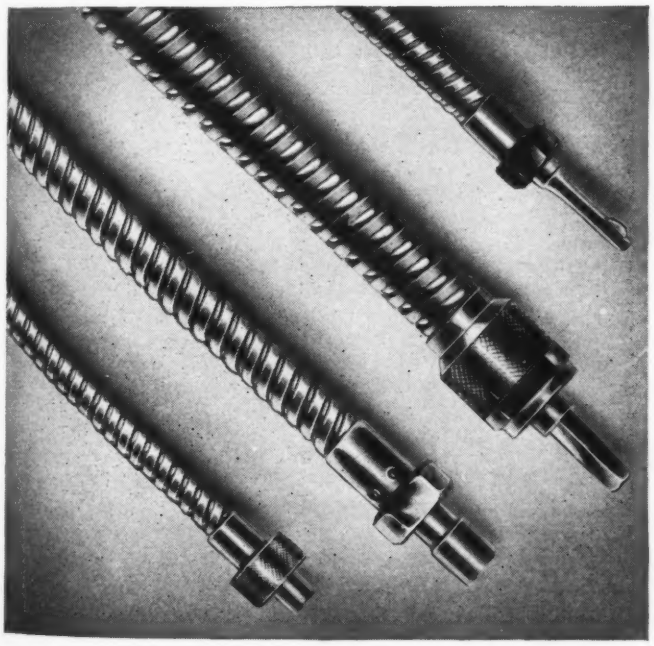
Putting Enemy-Owned Patents to Work

ENEMY-OWNED patents representing some of the finest research achievements of modern science are now being developed to help win our battles abroad and to strengthen our civilian economy at home. The Office of Alien Property Custodian is bringing the vested patents to the attention of those who can use them in order that they may be developed and used. Each vested patent and patent application has been listed under the standard Patent Office classification of patents. These lists are available on payment of 10 cents for each numbered classification, except for nine of the larger classes where the charge is 25 cents each. Complete catalog is available for $5. Classified lists and catalogs may be obtained from the Chicago branch of the office of Alien Property Custodian. Printed copies of vested patents and drawings and specifications of vested patent applications may be obtained from the Commissioner of Patents, Washington, D. C., for 10 cents each. In addition, libraries of copies of vested patents have been opened in New York, at 120 Broadway, and in Chicago, in the Field Building.

The procedure for obtaining a patent license is simple. A letter of application is sent to the Office of Alien Property Custodian, Washington, D. C. Besides giving his name, nature of his business, citizenship, etc., the applicant is requested to state his facilities, if any, for using the invention sought to be licensed, for example, actual equipment, technical skill and available or proposed capital, and the purpose for which the license is needed and its relation, if any, to the war program. If the applicant is a reputable American firm or individual—and a brief investigation will reveal this—the license will be issued within a few days. License application fee is $50 for each single patent plus $5 for each additional related patent. Licenses, which are royalty-free and nonexclusive, extend for the life of the patent unless revoked for failure to live up to the license agreement or unless the interest of the Government requires their revocation.



WALKER-TURNER FLEXIBLE SHAFTING



Is your problem the transmission of a small amount of power at an angle, or between two points not in a straight line? Or is it the matter of control of some mechanical or electrical impulse from a point relatively remote?

In either case, the chances are that Walker-Turner Flexible Shafting can do the job more effectively than any other means. For many years Walker-Turner has manufactured flexible shaft machines, which are today used by the thousands throughout industry. The specialized knowledge of the design of flexible shafting which we have gained in this work, has been applied to many war applications of power transmission and remote control, under the most exacting conditions.

We offer this experience for the assistance of those designing engineers who have problems involving the use of Flexible Shafting.

WALKER-TURNER COMPANY, INC. • 2363 Berckman St., Plainfield, N. J.

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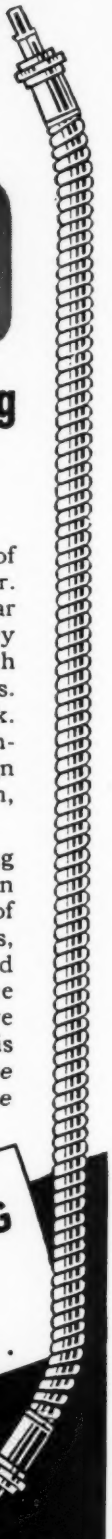

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ASSETS to a BOOKCASE

Mechanical Vibrations

By R. K. Bernhard; published by the Pitman Publishing Corp., New York; 139 *pages,* 6 *by* 9 *inches, clothbound; available through* MACHINE DESIGN, $3.00 *postpaid.*

In this book vibration problems are treated with the minimum of mathematics, bearing in mind the requirements of those who have studied little dynamics. The book is divided into two parts covering, respectively, physical phenomena and methods for measuring vibrations. Engineers already familiar with the fundamentals of vibration analysis will be chiefly interested in the second part because of the discussion of dynamic measuring instruments and dynamic testing methods. Much of this material has not hitherto been published in such convenient form.

□ □ □

Merriman's Strength of Materials

Eighth edition, revised by Edward K. Hankin; published by John Wiley & Sons Inc., New York; 148 *pages,* 5½ *by* 8½ *inches, clothbound; available through* MACHINE DESIGN, $1.50 *postpaid.*

In this revised edition of a well-known text emphasis has been placed on practical rather than highly technical aspects of the subject. Explanatory material has been added, especially in the earlier chapters, with the intention of associating the principles discussed with experiences familiar to the reader. It should be pointed out that the book is elementary in scope and avoids the use of calculus, many of the equations being presented without derivation. As a basic text for those with little technical or mathematical background the book should serve a useful purpose.

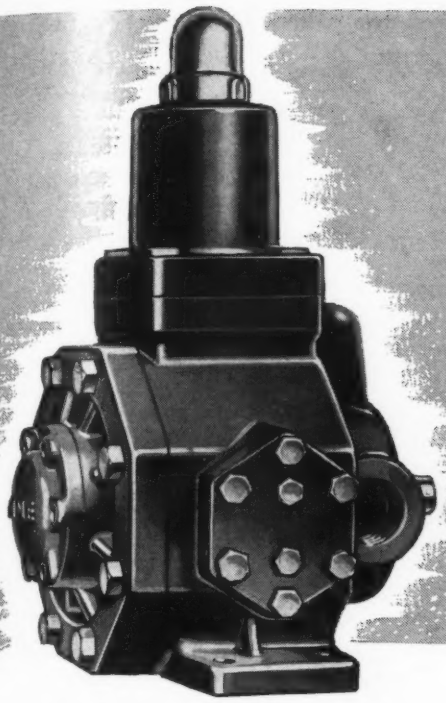
□ □ □

Lubrication

By A. E. Norton, late Gordon McKay professor of applied mechanics, Harvard University, edited by J. R. Muenger; published by McGraw-Hill Book Co. Inc., New York; 244 *pages.* 6 *by* 9 *inches, clothbound; available through* MACHINE DESIGN, $3.00 *postpaid.*

Technical papers on lubrication, though indicative of the importance of paying proper attention to the design of bearings for machines, enjoy a limited audience because many engineers are not familiar with basic theory and principles of lubrication. To give the engineer the proper background and bring him up to date on the subject, this book has been prepared.

Based on notes used by the late Professor Norton in a course on lubrication and bearings, the book is noteworthy



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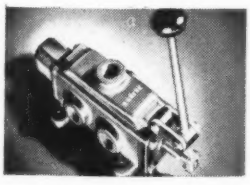

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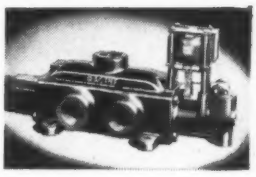

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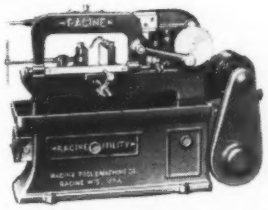

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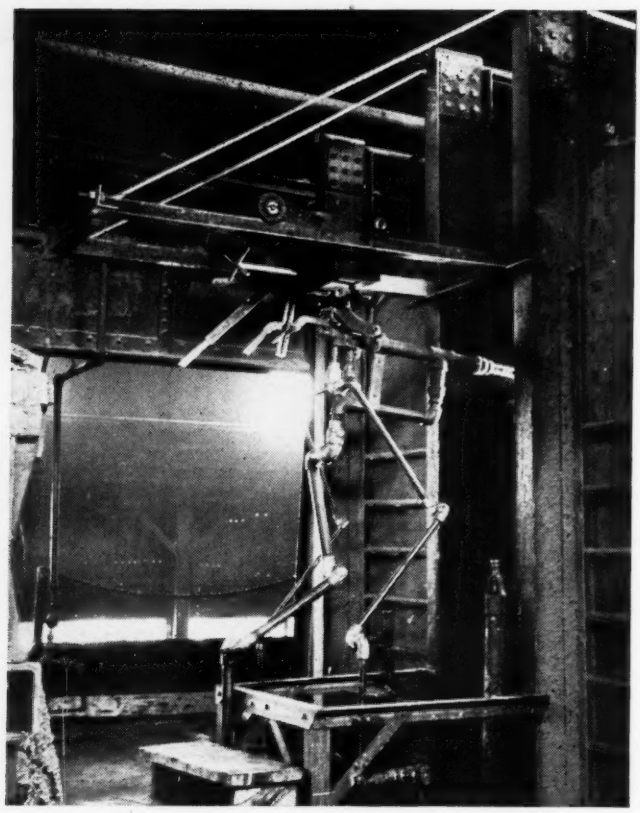

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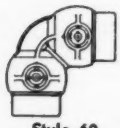

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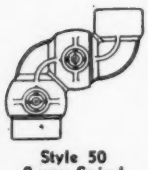

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for its clear and direct style. Although the subject of fluid-film lubrication is associated in the minds of engineers with the higher and more formidable branches of higher mathematics, the book has none of the appearance of a mathematical treatise. While the basic concepts are explained and formulated mathematically, the author does not permit the reader to become bogged down by the details of mathematical development. Consequently the results and their practical significance leave a stronger impression than do the formulas.

Following an introductory chapter, subsequent chapters are devoted to fluid friction and viscosity; thin-film friction and oiliness; properties of lubricants; hydrodynamic theory for slider bearings without leakage; slider bearing with variable viscosity; full journal bearing without side leakage; partial bearings and fitted bearings without side leakage; slider bearings with side leakage; journal bearings with side leakage; thermal equilibrium, bearing loads and design practices; grooving, application of lubricants and materials for bearing construction; and ball, roller and needle bearings.

One of the difficulties in studying the subject has been the variety of nomenclature used by various authors. Professor Norton has followed the accepted symbols as far as possible and has listed them in a two and one half page nomenclature section. A list of 63 references and a brief index complete the book.

□ □ □

Marine Engineering

By J. M. Labberton, Lieutenant Commander, U.S.N.R.; published by McGraw-Hill Book Co. Inc., New York; 439 pages, 6 by 9 inches, clothbound; available through MACHINE DESIGN, *$4.00 postpaid.*

Designed primarily for those who already have a grasp of engineering fundamentals, this is a concise, practical book that will appeal to engineers because of its straightforward presentation. That the engineering of a modern ship involves a great deal more than just the provision of propelling machinery is indicated by the fact that discussion of propulsion equipment occupies considerably less than half of the book.

Beginning with a brief chapter on hull design and resistance of ships, the author goes on to discuss propellers and propulsion shafting in sufficient detail to enable the reader to follow the principal design calculations.

Propelling machinery is covered in a series of chapters on reduction gearing, marine fuels and combustion, steam generators, and turbines, with later chapters on astern operation and electric drive. While design of turbines and reduction gearing is covered fairly extensively, no discussion is included on reciprocating steam engines or diesel engines, although problems which arise in the application of the latter to marine use are covered in a later chapter. Inasmuch as the performance of the turbine enters into the marine engineer's calculations while that of diesel is more or less independent of other factors, this apparent unbalance appears to be justified.

Later chapters cover in turn marine pumps, heat exchangers, forced draft and duct work, marine electrical

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This experience has been oft repeated. Ampco Metal, that sturdy alloy of the aluminum bronze class, steps in and outperforms ordinary bronzes—not only in die service, but as parts for machine tools, aircraft, ordnance, and other equipment. Ampco Metal stands up against wear, fatigue, and abuse.

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engineering, refrigeration, feed systems, heat balance, the diesel ship, layout, naval vessels, and ship's trials. As already indicated, discussion of auxiliaries, especially pumps and heat exchangers, is quite extensive, while the chapters on electrical engineering and refrigeration constitute excellent reviews of these subjects.

The book is largely made up of material which has been presented in graduate courses at New York University and in war training courses for engineers working in engineering departments of ship and Navy yards and marine engineering organizations.

□ □ □

Aviation Mechanics Simplified

By H. L. Williams, edited by M. H. Froelich; published by A. Neil Sawyer Co., New York; 576 pages, 6 by 9 inches, clothbound; available through MACHINE DESIGN, *$3.95 postpaid.*

Although this is a popular book intended as a practical self-instruction manual for the aircraft and engine mechanic, designers may be interested in the numerous photographs and drawings of airplane components, hydraulic systems, etc. Written in a racy style which readers of the usual type of textbook may find refreshing, the text material is of an extremely elementary nature.

□ □ □

Heating Ventilating and Air Conditioning Guide

Twenty-first edition, published by the American Society of Heating and Ventilating Engineers, New York; 1160 pages, 6 by 9 inches, clothbound, available through MACHINE DESIGN, *$5.00 postpaid.*

Departures from standard and commonly accepted good practices necessitated by the war are indicated in a new supplement incorporated in the latest edition of this annual handbook. This emergency war practices supplement includes specific recommendations for fuel saving as well as information on the availability of materials and equipment and the substitutes that must be accepted.

A new chapter has been added covering abbreviations, symbols and standards including a compilation of state laws and codes. Other chapters have been rewritten and expanded to include new information.

New standards covering the classification and test requirements for rubber compounds suitable for automotive uses other than tires and tubes are included in the 1943 edition of the SAE Handbook. Ferrous and nonferrous material specifications have been revised to include emergency alternatives developed during the past year. Additions and revisions to SAE Aeronautical Materials Specifications, Aeronautical Standards, Aeronautical Recommended Practices and Aeronautical Information Reports also are listed in the new Handbook, while a section on War Emergency Recommended Practices has been added.

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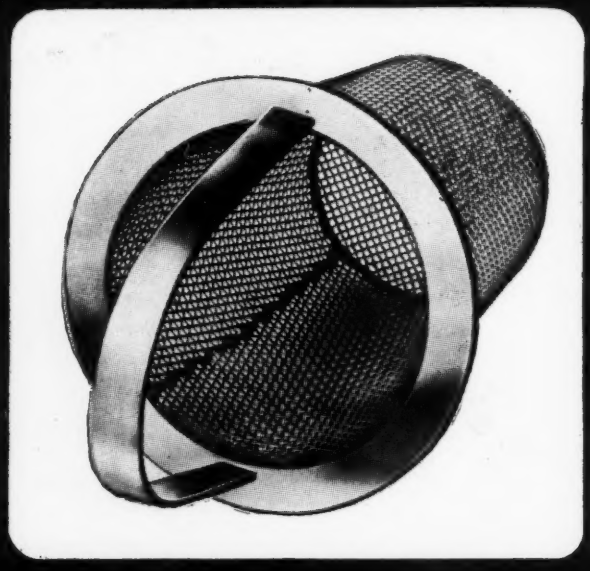

NO RISK OF BURNING IN JOINING LIGHT TO HEAVY GAUGE

PROBLEM

To join the thin bronze mesh of these oil tank hose strainers to the thick brass frame without overheating and burning the mesh. With high temperature fusion welding such damage was prevalent. As a result vital metal and man-hours were needlessly wasted on a great number of the units produced.

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How the Army Approves Redesigns

(*Concluded from Page* 117)

given to the task of supplying ordnance materiel for these branches, not only for the United States armed forces, but also for a substantial part of that now being used by our allies.

In a program of such magnitude, critical materials, skilled labor and complicated machinery must be utilized at their maximum efficiency. Where practical, substitutes must be found for and full use made of such basic materials as silk, rubber, tin, zinc, aluminum, copper, nickel, etc. The constantly increasing demand for personnel in the armed forces requires that industry, where possible, convert from male to female labor. In like manner, the present crisis makes it mandatory to put in effect the best foundry and machine shop practices available.

Utilizing Resources and Facilities

Industry is steadily increasing production of vitally needed raw materials. What the maximum production or the amounts needed will be, as the tempo of the present conflict develops, we have no way of knowing. Therefore, the objective of the Army Ordnance department is to utilize this production and all available supplies to the fullest extent.

The first job of industry, that of converting from peace to wartime production with prevailing specifications and designs has been completed. The next objective and the subject of this article is the question of possible changes in specifications or redesign of ordnance material tending toward conservation or fullest utilization of critical materials.

Army Ordnance is anxious to receive suggestions from industry for design or specification changes and is now geared to place quick approval on ideas or suggestions worthy of acceptance. No design or specification change can or will be approved until its field performance characteristics are proved beyond a doubt.

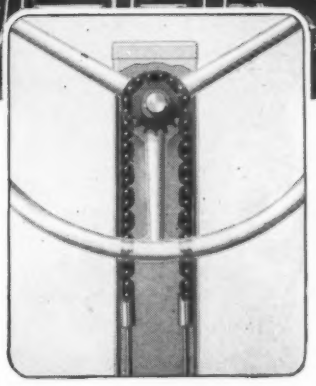
Official Action on Redesigns Is Prompt

General Levin H. Campbell, Chief of Ordnance, appreciating the importance and possible benefits to be gained by interchange of ideas between industry and Ordnance engineers, established on August 1, 1942, in each of the 13 Ordnance Districts a Conversion Engineering section. Each section has been set up for the purpose of expediting the processing of suggestions pertaining to redesigns or changes in specifications that affect materiel in the ordnance district in which it is located. Those found to have sufficient merit are forwarded to Washington headquarters for final inspection and official acceptance or rejection. District offices as well as headquarters are now so staffed that unless redesign is extremely complicated or needs a great deal of testing, official acceptance or rejection of suggestion may be had thirty days after receipt at the Ordnance district office.

Flying Drives!

New, Improved Link-Belt Silent Chain increases efficiency of Aircraft Controls!

Chain can fight, too. It's doing a big war job in many types of fighting equipment as well as on the production front. New types—designed for high precision performance—are helping make our planes, our tanks and other vital weapons the finest in the world. Link-Belt engineers have helped solve many critical design and production problems by their ingenious and efficient applications of chain. Link-Belt, through its vast experience and extensive producing facilities, has developed and expanded its line of chains and sprockets into scores of standard types and sizes for every conceivable purpose. Wherever chain is needed—for power transmission or for conveying—remember, it's Link-Belt for Chain!



Link-Belt Precision-Built Aircraft Silent Chain is a special development, to meet the needs of the aviation field. The distinctive tooth and link form of this improved chain minimizes the effect of chordal action and assures smooth, positive operation even over extremely small sprockets.

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Improving Fatigue Strength of Machine Parts

(*Continued from Page* 129)

any surface layer subjected to cyclic tension stress should be reduced or removed or, better still, converted to compressive stress by suitable treatment because all fatigue failures are due to tension stresses.

In connection with machining damage, an interesting observation has recently been made which indicates that the layer injured by machining is deeper than is generally believed. It also shows that the injured material does not recover by heating for long periods at high temperatures. *Fig.* 13, left, shows a bar of 4615 steel as it appeared after rough machining on a shaper. This piece was then carburized for eight hours at 1700 degrees Fahr., cooled in the box, reheated at 1500 degrees Fahr., quenched in oil and drawn at 300 degrees Fahr. for one hour. The machined surface was then ground in a direction at right angles to the shaper marks to a depth of .0055-inch below the last visible tool mark after which it was polished as shown in *Fig.* 13 (center). Finally the polished surface was shot blasted, whereupon the machining marks (vertical lines) and the grinder marks (horizontal lines) reappeared as shown in *Fig.* 13, right, showing that the material is not uniform in resisting the shot blasting, notwithstanding the long period at elevated temperature. There is no evidence at present that the effect brought out by this experiment is significant in fatigue. It is presented here to emphasize that there is much that is not known about our materials and processes.

Allow for Elastic Deflections!

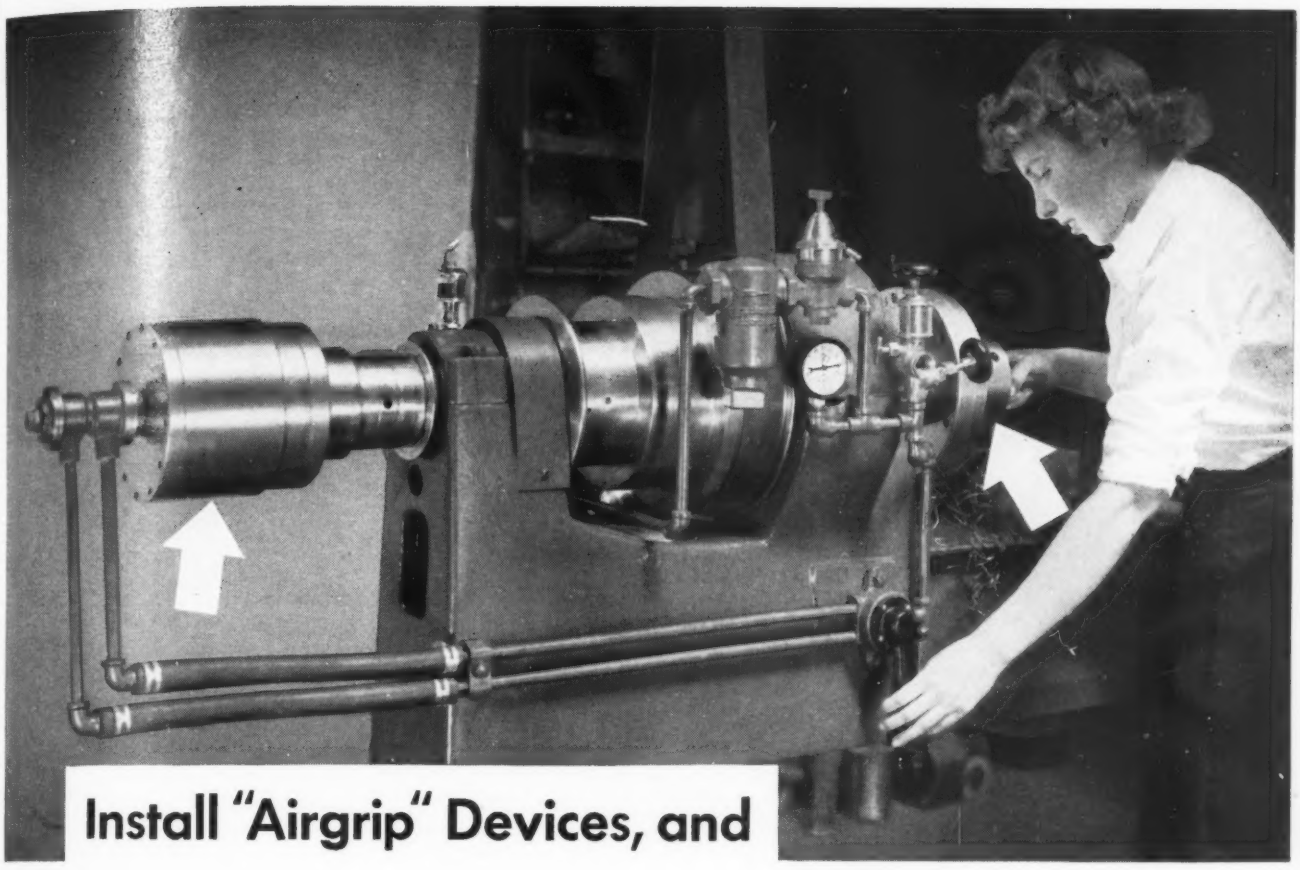
A common cause of fatigue vulnerability is the belief apparently held by some designers and engineers that structural materials are rigid. Many fatigue failures can be traced to elastic deflection for which no allowance was made in the design. Deformation of mating parts may be such as to concentrate the load in a small region.

For example, under operating conditions a crankshaft may be so elastically deformed in twisting and in bending that the bearings are only partially effective in supporting the load. Bearings frequently are found to be plastically deformed or worn "bell-mouthed" to accommodate the elastic gyrations of the crankshaft.

Perhaps the most generally misunderstood of all machine elements are gears. As ordinarily designed there is only one thing certain about gears and that is that they will not function as intended by the designer. When laying out a set of gears on the drafting board the mating teeth are represented by parallel straight lines over which the load is assumed to be uniformly distributed, but no matter how carefully the gears are cut and heat treated the mating teeth will never again be parallel except by accident and then only through a small load range.

The nature of the contact between two mating gear teeth is influenced by:

1. Elastic characteristics of the housing in which they are contained
2. Elastic characteristics of bearings by which they are



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She'll beat Bill's output by 25%, or more

This is the old "strong-man," time-wasting, operator-tiring, high-unit-cost way of holding parts. Hour after hour the operator wrestles with a wrench—sapping his energy, increasing scrap, holding back production, and wasting critical machine hours.

Yes, she can take Bill's place and beat his best production record by 25%, or more, when you install "Airgrip" Holding Devices. They are available now, and installation is simple and fast.

She will quickly learn to use "Airgrip" Devices, producing at the full capacity of the machine—a thing Bill never could do with all his bulging muscles. And, because "Airgrip" Devices are so easy to operate, she will work a full turn and have output on schedule when the whistle blows.

It will pay you to investigate the advantages of "Airgrip" Holding Devices—increased production of 25% or more, lower cost per piece part, reduced spoilage, minimum operator fatigue.

"Airgrip" engineers are ready to help you on any problem where air can be used for fixtures or chucking purposes.

Anker-Holth Mfg. Co.

"Airgrip" Chuck Division

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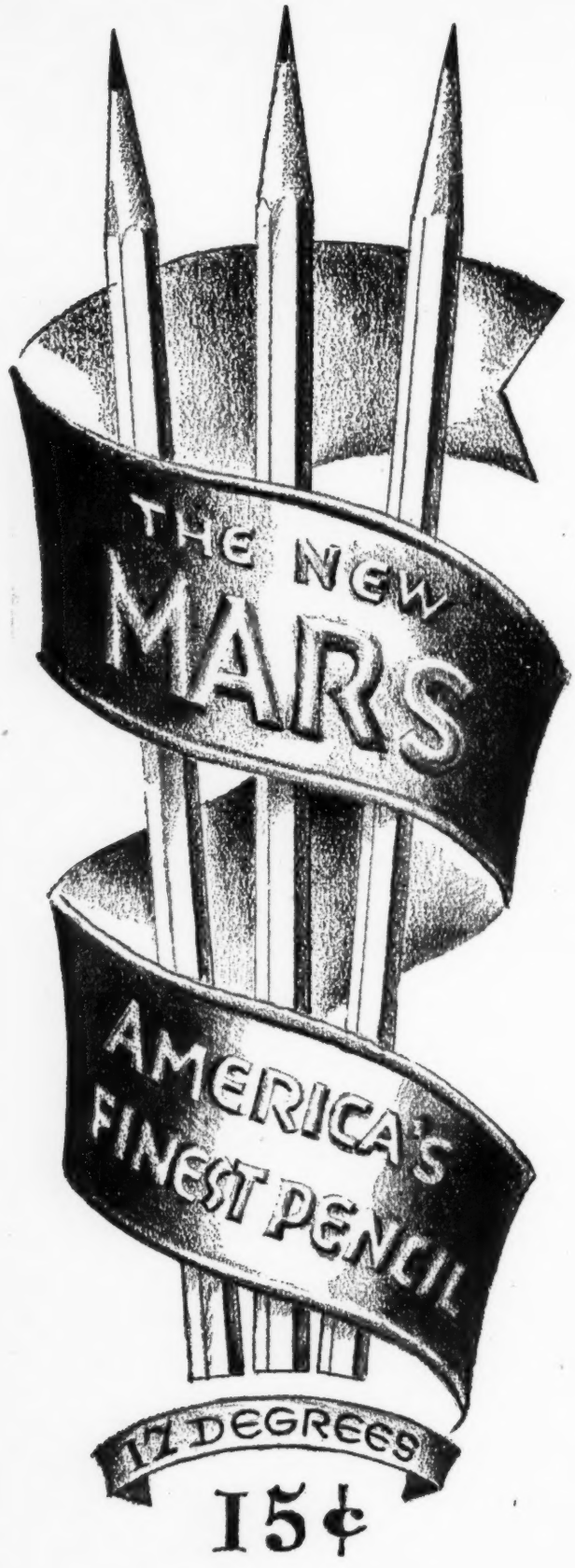

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supported
3. Elastic characteristics of the shafts upon which they are mounted
4. Elastic characteristics of the gears themselves
5. Accumulated dimensional errors in all the supporting parts as well as errors in the cutting of the gear
6. Necessary and accidental clearances in the supporting parts
7. Misalignment of supporting parts through thermal expansion
8. Amount and nature of the warpage in heat treating—to give the metallurgist some of the responsibility.

The result is that it is virtually impossible that the parallelism visioned by the designer can exist in practice. If it should chance that two mating gear teeth are parallel at some load they cannot be parallel at any other load because the elastic deflections of some of the supporting parts are not linear with respect to the load. As ordinarily designed, the load on gear teeth is never uniformly distributed over the length of the teeth but is always concentrated toward one end of the teeth. Load localization cannot often be seen by examination of a gear that has seen service because usually each tooth of each gear makes contact with all of the teeth in the mating gear and the summation of all contacts under all load conditions will be seen by the examiner.

Inadequate Support Caused Gear Tooth Failure

A gear that failed in service was "rescued" while on its way to the metallurgical department to find what was wrong with the material to cause the fatigue failure. The failed tooth was broken at one end which, incidentally, is typical of almost all failed gear teeth. An adjoining unbroken tooth indicated that failure occurred because only a small part of the tooth was actually supporting the load in spite of the generous tooth length provided by the designer. This gear would have been just as durable had it been designed to one-fifth the tooth width actually provided. Clearly this was a mechanical and not a metallurgical problem. The real trouble was inadequate support of the gears and other mechanical errors as commented previously.

It may be argued fairly that this was an unusually severe case, not typical of gear fatigue. Actually the most unusual thing about it was that it could be diagnosed before it was cut into sections and the evidence etched away as so often happens in metallurgical examinations!

Many materials and processes have been graded and are still being graded by laboratory tests which are now known to have been very costly to industry. For example, the fiction that a carburized part should have a hard case to resist wear, and tough core to resist breakage, arose from laboratory impact tests. In these tests the strength of the part was judged by the number or intensity of hammer blows it would withstand before fracture. Since gear teeth resisted impact fracture in accordance with the physical properties of the core, it seemed logical to specify heat treatments to bring out the best compromise between the imagined requirements of the case and the core. Being compromises, these heat treatments were not the best for either region.

If, instead of counting the number of impacts or measuring the intensity of hammer blows to produce fracture, the

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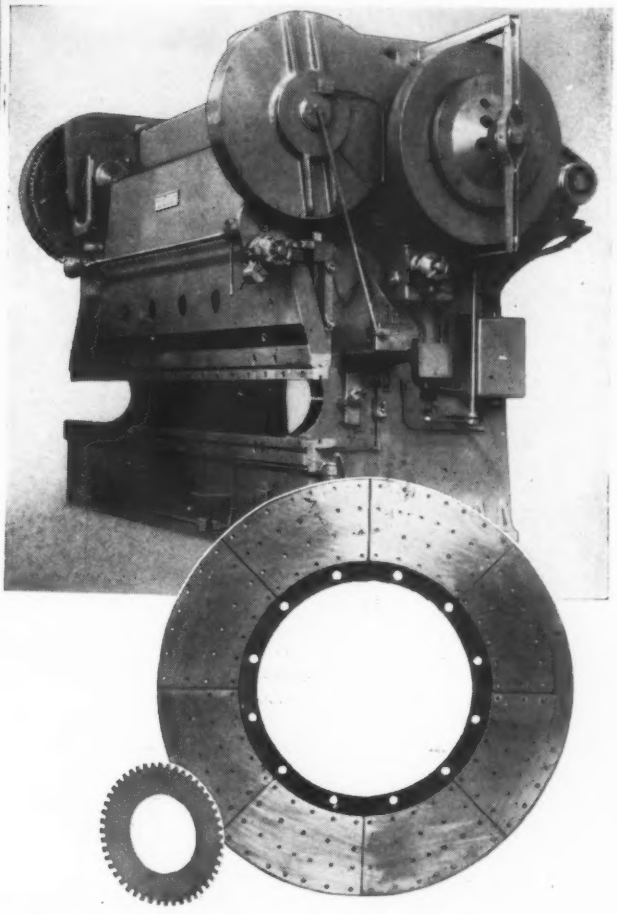
Higher and higher go America's combat planes, as engine superchargers become more powerful and dependable. Operating at speeds up to 24,000 r.p.m., the 2-stage geared superchargers are equipped with VELVETOUCH clutch facings. This amazing friction material has also proven its dependability in landing wheel brakes and in clutches on bomb doors, wing flap controls and gun turret mechanisms. Such established performance, under the most severe conditions, makes VELVETOUCH the logical choice for clutch facings and brake linings in earth-moving equipment, in marine and industrial machinery, in oil well and coal mining equipment. Specify VELVETOUCH for long wear and trouble-free operation!



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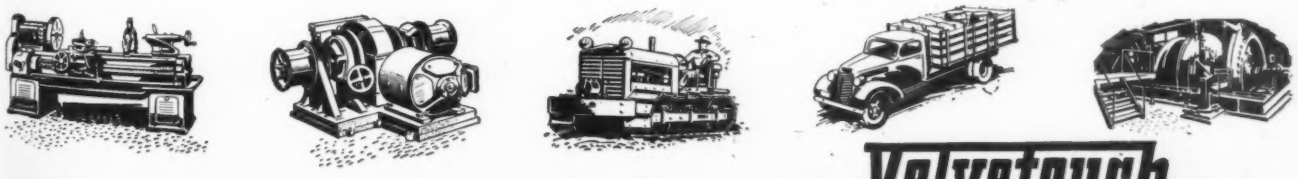
VELVETOUCH is an all-metal friction material—a combination of sintered powdered metals, compressed and welded to a solid metal backing. In this press brake the 6" VELVETOUCH clutch facing and 22" VELVETOUCH brake disc help to speed production by their smooth, positive operation and uniform coefficient of friction.



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Built in three standard sizes, ⅜, ½, and ¾ inch, for use on initial pressures up to 150 lbs. Write for Bulletin 56-MD.

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gear tooth had been examined after the first impact, the tooth would have been found bent and, therefore, ruined, and it would make no difference how many more blows were required to fracture the tooth.

This compromise heat treatment resulted in reducing the quality of millions of gears before it was realized that gear teeth fail by fatigue and that fatigue failure, for the usual depth of carburization, always originates at the surface of the case. From this evidence it became clear that heat treatment should consider the requirements of the carburized case only, and that the properties of the core were relatively unimportant, because in bending and in torsion the core serves mainly as a stuffing for the case.

Several kinds of impact tests are still being used and impact specifications appear in many drawings but no man can explain and substantiate the significance of the test in terms of service strength of machine parts.

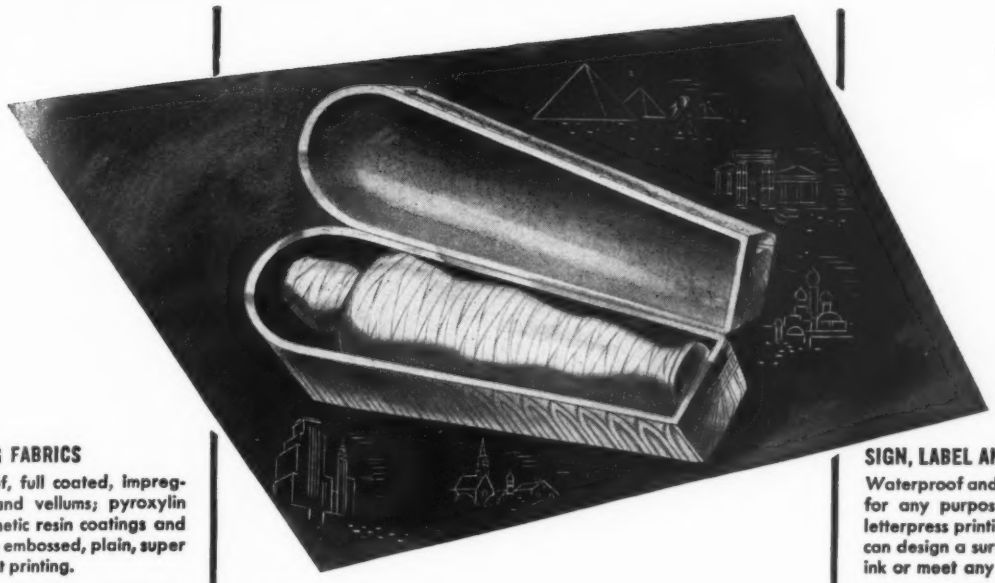
Ductility *Versus* Hardness for Dynamic Loads

Elongation and reduction of area are carefully measured and are prominent in specifications, but their meaning in terms of serviceability of machine parts is not known. It is said that "brittleness" must be avoided but no matter how brittleness is defined it does not explain why this property is necessarily more harmful than ductility. Most machine parts that are plastically deformed are just as surely failed as if they were broken. The belief is that machine parts generally must possess relatively high ductility and must therefore be heat treated to develop this property. However, for really severe dynamic loads, ductility is forgotten and high hardness that certainly is well within the range of brittleness in the usual meaning of the word is specified. Wristpins, gear teeth, ball bearings, roller bearings, shafts and cams are hard; they are strong and fatigue resistant because they are hard. When hardness is obtained by nitriding, brittleness is not feared, because such surfaces are not notch sensitive, being stressed in compression.

Notch sensitivity is probably the inability of a nonductile material to yield locally and thus reduce tension stresses in local highly stressed regions, such as notches and scratches. The amount of ductility required to overcome brittleness depends upon the amount of yield necessary to reduce local tension stresses. If the surface is sufficiently prestressed in compression, local yielding is not required and therefore nonductile materials will not be brittle. As understanding of brittleness improves, steels may be used at higher hardness in many parts for which ductility is now specified. Gain will ensue from the greater inherent strength as well as from the increased strength obtained by compressively stressed surfaces.

Most significant of the easily performed laboratory tests is hardness. Since the static strength of most materials is roughly proportional to hardness, the approximate static strength of a part is known if the hardness is accurately measured. However, the popular hardness testers such as brinell or rockwell are incapable of the accuracy that is required because they penetrate too deeply into the material being tested, and therefore they do not measure the characteristics of that most important part of the material, the surface layer.

Fatigue tests of full scale machine parts have been



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made by laboratories for a long time but since these tests have usually been for the purpose of comparing one material, design or process with another material, design or process, the tests have been run at arbitrary constant loads without thought to the fatigue curve characteristics and often without adequate correlation with service requirements. Because of this procedure, little use has been made of the vast quantities of fatigue data now locked in files in so far as establishing a basis for evaluating a material, design or process for the future is concerned.

In the few cases where fatigue data on machine parts have been properly organized, they reveal astonishing amounts of fundamental information about the many variables that are present in machines elements, many of which are not even qualitatively revealed by ideal laboratory fatigue specimens.

In practical fatigue testing of machine parts, it should be obvious that comparisons of materials, designs or processes cannot be made unless tests are run to failure and the comparisons made on the number of stress cycles each will endure. This is true whether or not the part being tested is required to withstand, in service, a very large number of stress reversals at maximum load such as a crankshaft or a relatively small number of stress reversals at maximum load, such as chassis springs. Since all representative tests are made at loads that result in failure by fatigue, our interest lies not in the fatigue endurance limit where, for steel under most test conditions, life is infinite, but in that portion of the fatigue curve to the left of the "knee" where life is finite, that is, the sloping part of the curve.

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Evaluating Torsional Stresses by Membrane Analogy

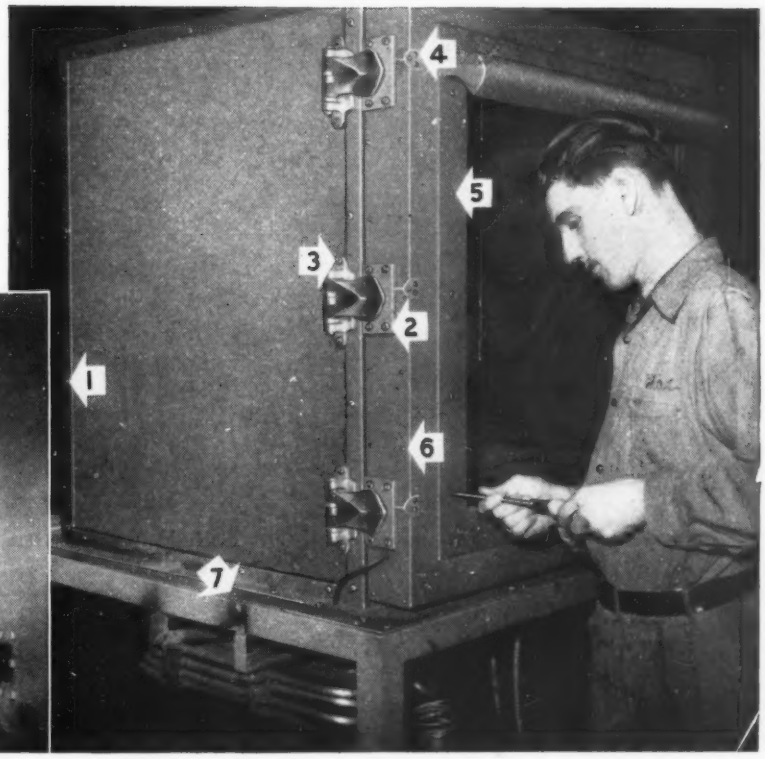
(*Continued from Page* 123)

angle of twist show that it is necessary to determine the slopes at points on the two films and also the volumes bounded by the deflected membranes and their original boundaries. Then Equations 12 and 13 give, respectively, the shear stress and angle of twist in terms of the twisting moment M_t on the section.

Applications of the experimental procedures in the membrane method were made by Griffith and Taylor(8). Results of comprehensive studies of aircraft members have been reported by Trayer and March(9). Their investigations cover the experimental procedure and theory and give shear stress formulas and constants for various types of cross sections.

For some cross sections, approximate values for the shear stresses and angle of twist can be determined without performing the actual experimental work. That is,

Question every fastening job



Mobile Refrigeration, Inc., Long Island City, New York, chooses P-K Self-tapping Screws for Assembly of Several Different Materials

1. Type A — Driven through steel angles into Masonite housings.
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3. Type A — Two screws in each of three hinge butts. Fastening is steel plate to birch.
4. Type A — Two screws in each of three adjustable door fasteners. Fastening is steel plate to birch.
5. Type A — Fasten frame for door glass. Driven through steel into birch.
6. Type A — Hold door armor in place. Driven through steel into birch.
7. Type Z — Fasten chamber unit to base casting. Driven through Masonite into ⅛" angle iron.
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260 TAPPING OPERATIONS ELIMINATED ON EACH UNIT-

Man-hours and tools saved—Assembly made stronger with P-K Self-tapping Screws

Assembly of this high altitude test-and-calibration-chamber for aircraft and electronic instruments was greatly simplified, and the product made stronger, when the maker wisely "questioned every fastening".

Of more than 500 fastenings required, about half are metal-to-metal, for which machine screws were formerly used. When these were replaced by P-K Type "Z" Screws, 260 tapping operations were eliminated. Since P-K Self-tapping Screws tap their own strong threads as they are driven, one easy operation completes the fastening. They save the man-hours used up in tapping . . . they also eliminate grinding, breakage and replacement of hard-to-get taps.

Assembly of the unit also involves a large number of metal-to-wood and metal-to-Masonite fastenings. Experiments showed that P-K Type "A" Screws would afford much greater security than the conventional wood screws which had been used. Stronger fastenings result because P-K Type "A" Screws are threaded all the way to the head, and are uniform in dimension.

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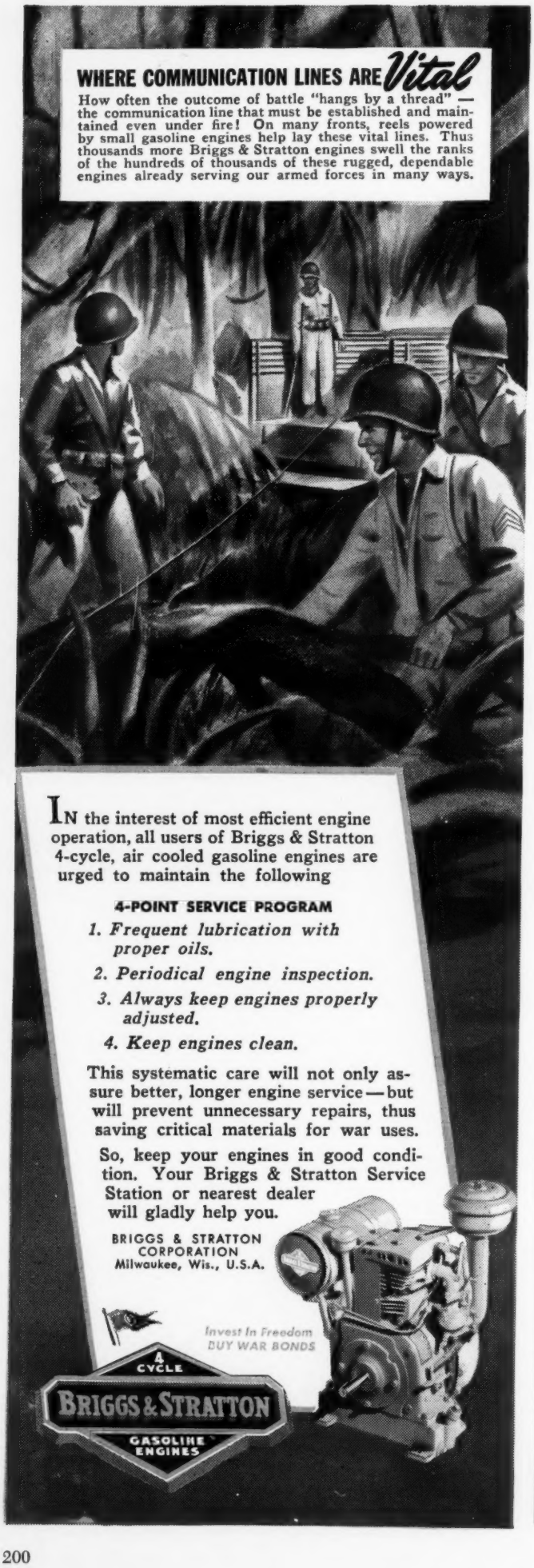
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for certain cross sections the shape taken by the film can be assumed. This procedure will be explained in the following.

In the case of a narrow rectangular cross section the membrane analogy can be used to give a simple solution for the torsion problem. Neglecting the effect of the short sides of the rectangle, the surface of the deflected membrane in the case of a rectangle can be assumed as cylindrical, *Fig.* 12. The maximum deflection of the membrane can be obtained from the deflection curve of a uniformly loaded string. This deflection can be obtained from *Fig.* 12*b*, since

$$\alpha = tan\ \alpha = \frac{4\delta}{c} = \frac{qc}{2F} \quad or \quad \delta = \frac{qc^2}{8F} \qquad \ldots\ldots (w)$$

The maximum shear stress, however, is the slope α provided q/F is replaced by $2G\,\theta$. That is, from Equation w,

$$(S_s)_{max} = \alpha = \frac{cq}{2F} = cG\theta \qquad \ldots\ldots (x)$$

The angle of twist is obtained from the fact that the torque is equal to twice the volume enclosed by the deflected membrane and the xy plane. This is approximately

$$M_t = (2b)\left(\frac{2}{3}c\delta\right) = \frac{qbc^3}{6F} \qquad \ldots\ldots (y)$$

Replacing q/F by $2G\,\theta$,

$$M_t = \frac{bc^3G\theta}{3} \quad or \quad \theta = \frac{3M_t}{bc^3G} \qquad \ldots\ldots (14)$$

Placing this value of θ in Equation x, the maximum shear stress is

$$(S_s)_{max} = \frac{3M_t}{bc^2} \qquad \ldots\ldots (15)$$

Equations 14 and 15 can be used for determining approximately the maximum stresses and the angle of twist in the case of thin-walled bars, as shown in *Fig.* 13. This follows from the fact that the maximum slope of the film and the volume bounded by the membrane will be nearly the same in *Figs.* 13 as in the case where the members are rectangular with a width c and a length equal to the developed length of the center line.

An approximate solution of the torsion problem for thin-walled tubes can easily be obtained by using the membrane analogy. In this case the outer and inner boundaries of the section are located on different horizontal planes with the membrane connecting the boundary, *Fig.* 14. For a thin-walled tube the curvature of the membrane can be neglected. By the membrane analogy the shear stress is then uniform over the wall thickness and equal to

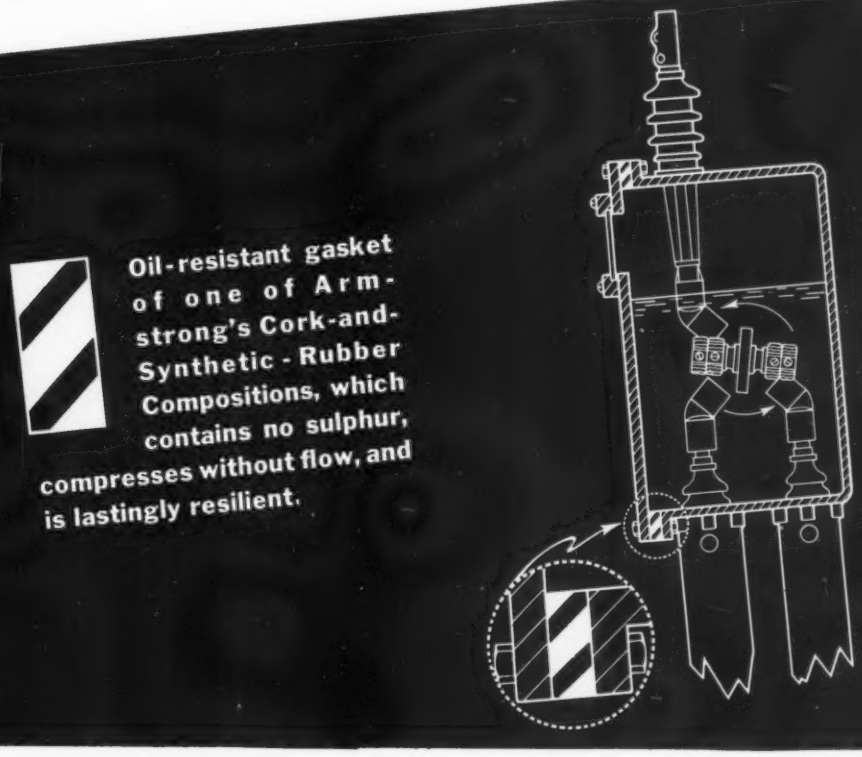
$$S_s = \frac{\delta}{h} \qquad \ldots\ldots (z)$$

The volume included between the surfaces mm and nn is the area A bounded by the dotted center line and multiplied by δ. Then by the membrane analogy,

CASE HISTORY No. 204

GASKETS

PROBLEM: To find a permanently resilient, sulphur-free gasket for the cover of an oil-filled electric switch.



Oil-resistant gasket of one of Armstrong's Cork-and-Synthetic-Rubber Compositions, which contains no sulphur, compresses without flow, and is lastingly resilient.

AN oil-filled selector switch required a gasket, between the side cover and the metal housing, to seal in the oil and to seal out moisture. Besides having to be oil-resistant and moisture-resistant, the gasket material had to be free of sulphur—which would contaminate the oil. It had to be compressible enough to fill any irregularities in the surface of the cover or of the flange on the housing . . . and permanently resilient so that the gasket would be fit for re-use whenever the cover was removed. The switch manufacturer specified that the gasket must not extrude around the edge of the joint, so the material had to compress *without side flow.*

Solution

When the manufacturer described this problem to Armstrong's sealing specialists, they recommended one of Armstrong's Cork-and-Synthetic-Rubber Compositions. Gaskets cut from this material met all of the requirements and have given trouble-free service for the past several years.

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$$M_t = 2A\delta \quad \ldots\ldots (aa)$$

From Equations z and aa,

$$S_s = \frac{M_t}{2Ah} \quad \ldots\ldots (16)$$

The angle of twist can be determined by considering the equilibrium of the membrane within the dotted line. For equilibrium, if F is the tension per unit length of the film,

$$\int F\alpha ds = qA \quad \ldots\ldots (ab)$$

where α is the slope of the film.

By the membrane analogy the slope α is the shearing stress. Using the condition $q/F = 2G\theta$,

$$\alpha = S_s\left(\frac{q}{F}\right)\left(\frac{1}{2G\theta}\right) \quad \ldots\ldots (ac)$$

Placing the value of α from Equation ab in Equation ac,

$$\int S_s ds = 2G\theta A \quad \ldots\ldots (ad)$$

Placing the value of S_s from Equation 16 in Equation ad, the angle of twist is

$$\theta = \frac{M_t}{4A^2G}\int \frac{c's}{\delta} \quad \ldots\ldots (17)$$

For tubes of uniform thickness, δ is constant and the angle of twist is

$$\theta = \frac{M_t s}{4A^2G\delta} \quad \ldots\ldots (18)$$

where s = the length of the center line of the ring section in the tube.

Values of the maximum shear stress and angle of twist for various types of cross sections have been tabulated by Roark (10). These results are based on theoretical and experimental procedures and the foregoing approximate analytical method. The table includes values for both solid and hollow cross sections.

Modified membrane analogy procedures have also been used in the solution of bending problems and to determine the sum of the principal stresses in photoelasticity.

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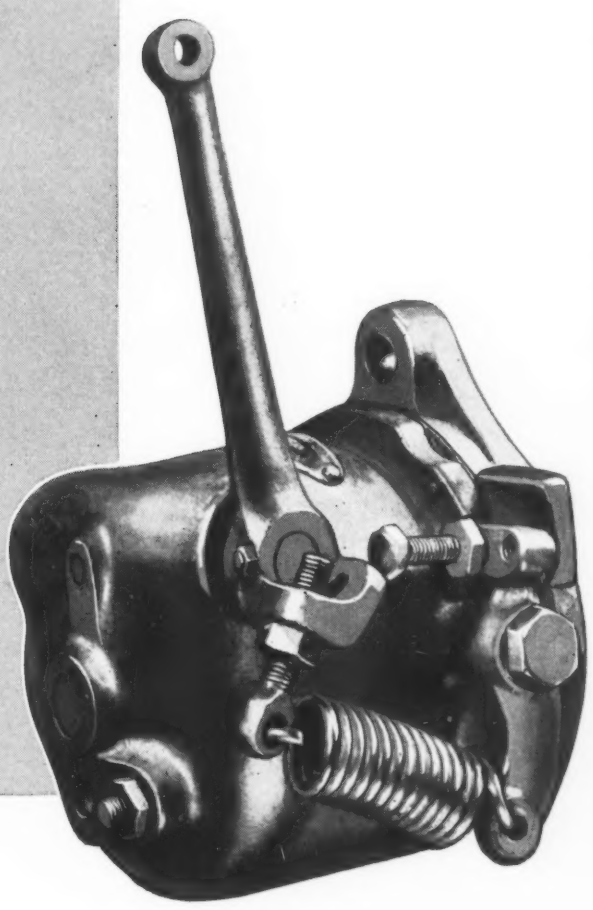

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IT is packed full of the information you need to select the *right* hydraulic cylinder *quickly*. Containing complete cylinder specifications, engineering data and charts, the new catalog is an informative time-saver for busy engineers.

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1765 ELSTON AVENUE • CHICAGO, ILLINOIS
RIVETERS • CYLINDERS • AIR HOISTS

BUSINESS AND SALES BRIEFS

EXPANSION of the bellows division of the Cook Electric Co. has resulted in the opening of a new plant for this division at 909 Diversey Parkway, Chicago. A modern testing laboratory with new facilities for altitude testing of aircraft work are included in the new quarters.

♦

Formerly assistant sales manager of S K F Industries Inc., Robert R. Zisette has been made general sales manager. Mr. Zisette has been with the company since 1921.

♦

Connected with Allis-Chalmers Mfg. Co. since 1925, L. W. Long, sales engineer in the company's Pittsburgh office, has been appointed sales engineer in charge of the mixed apparatus sales. This appointment has been made to coordinate sales involving the apparatus of more than one division of the electrical department.

♦

Fred O. Burkholder was recently named president of Ahlberg Bearing Co., succeeding the late C. J. Bender. He formerly was vice president. C. W. Pearsall, general sales manager, was named vice president.

♦

According to a recent announcement, the American Brake Shoe & Foundry Co., New York has changed its company name to American Brake Shoe Co.

♦

A member of the Electric Association for years, holding a number of offices in that organization, C. J. Maloney, Chicago district manager for Cutler-Hammer Inc., was recently elected president of the association for the 1943 term.

♦

As a result of the merger of Plaskon Co. Inc. and the Libbey-Owens-Ford Glass Co., James L. Rodgers Jr., formerly president of Plaskon, was elected vice president of the parent organization. The Plaskon company will be operated as the Plaskon division of Libbey-Owens-Ford Glass Co.

♦

Appointment of Judson C. Travis as vice president in charge of sales, Handy & Harman, New York, has recently been announced.

♦

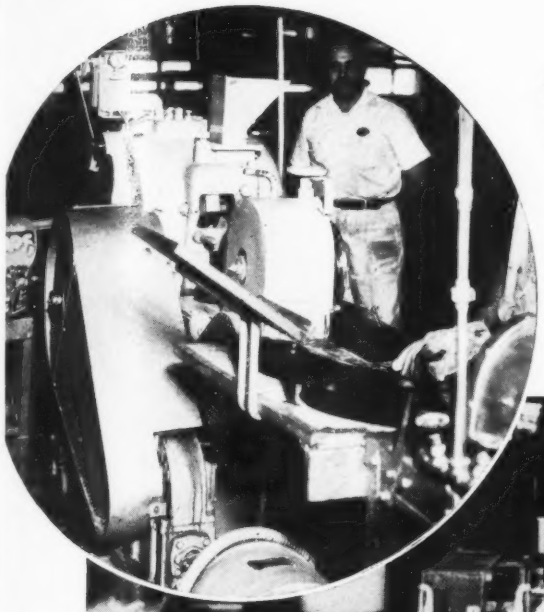
Associated with United States Rubber Co. since 1919, C. W. Higbee has been made manager of the newly organized wire and cable department. Mr. Higbee had been assistant manager and then manager of wire sales.

♦

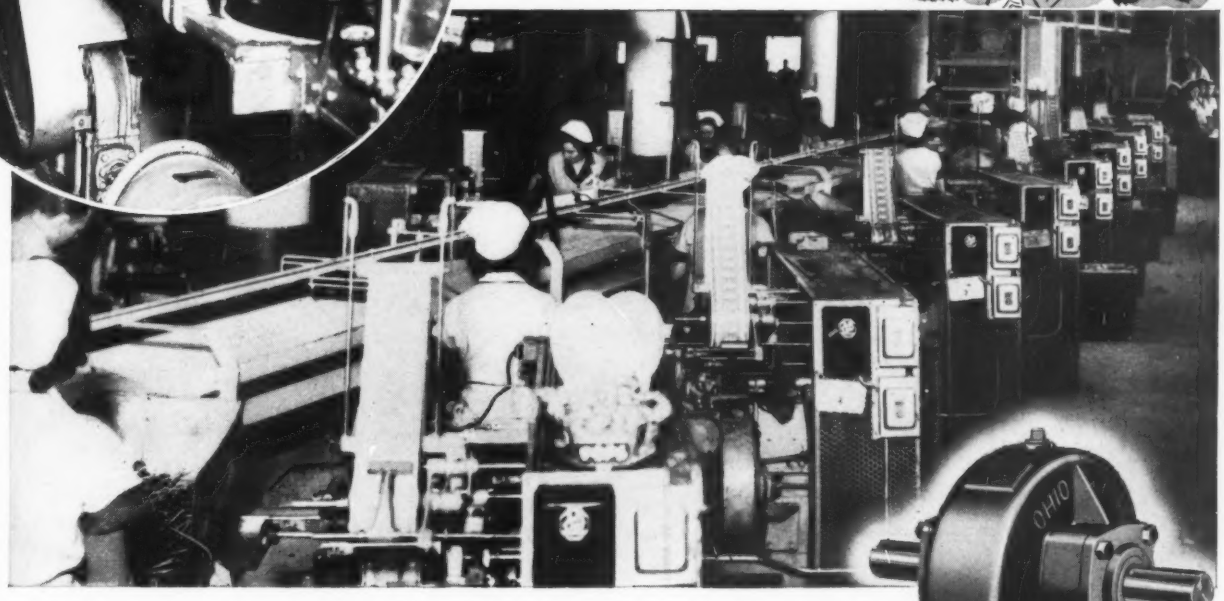
R. X. Raymond has been placed in charge of the Minneapolis office of D. O. James Mfg. Co., with offices in the Fawkes building.

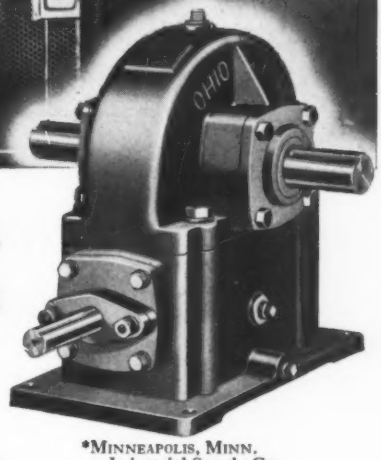
♦

Bunting Brass & Bronze Co., Toledo, O. has placed William T. Streicher in charge of bronze bearing sales. Formerly he had been in the company's Chicago office in charge of



TOOTSIE ROLLS for the Boys in Service!





OHIO GEAR REDUCERS help the Sweets Co. of America keep the millions of TOOTSIE ROLLS rolling to camps, ships and airfields

● In all the ballyhoo about guns, tanks, ships and planes, we're apt to overlook the fact that candy is fighting equipment, too. But Uncle Sam knows it. That's why so many millions of famous TOOTSIE ROLLS and other TOOTSIE confections, manufactured by the Sweets Company of America, are being bought by the army and navy.

Engineers and production men of the Sweets Company know that nothing but fullest mechanization of plant facilities can meet today's production demands. They know, too, that in such equipment, thorough reliability is *a definite must*. The failure of a single machine affects not only one department. It may tie up an entire production line.

That's why all Sweets Company conveyors and other power machines are driven through Ohio Gear Reducers. Experience with the first Ohio Gear units, installed a number of years ago (and still in service) proved the dependability and economy of these famous Reducers. So the natural selection for all succeeding requirements has been the Ohio Gear equipment best fitted for each particular power transmission job.

Helping to roll more TOOTSIE ROLLS to soldiers and sailors is another Ohio Gear Company contribution in our great war effort.

THE OHIO GEAR CO.
1338 E. 179th Street • Cleveland, Ohio

*New York City, N. Y.
Patron Transmission Co.
154-156 Grand Street

New England
George G. Pragst
332 Main St., Pawtucket, R. I.

*Los Angeles, Calif.
J. W. Minder Chain & Gear Co.
927 Santa Fe Avenue

Grand Rapids, Mich.
W. H. Slaughter
1924 Madison Ave., S. E.

*Pittsburgh, Pa.
Standard Machinists Supply Co.
South 2nd and McKean Street

Detroit, Mich.
George P. Coulter
322 Curtiss Building

**Stocks carried.*

*Minneapolis, Minn.
Industrial Supply Co.
717 S. Eighth Street

Buffalo, N. Y.
F. E. Allen, 2665 Main St.

*Kansas City, Mo.
Kansas City Rubber & Belting Co.
712 Delaware Street

*San Francisco, Calif.
Adam-Hill Co.
244-246 Ninth St.

Louisville, Ky.
Alfred Halliday, 330 Starks Bldg.

Indianapolis, Ind.
A. R. Young
635 N. Pennsylvania Ave.

St. Louis, Mo.
St. Louis Tool Co.
2319 N. Ninth Street

★ ★ ★

OHIO GEARS

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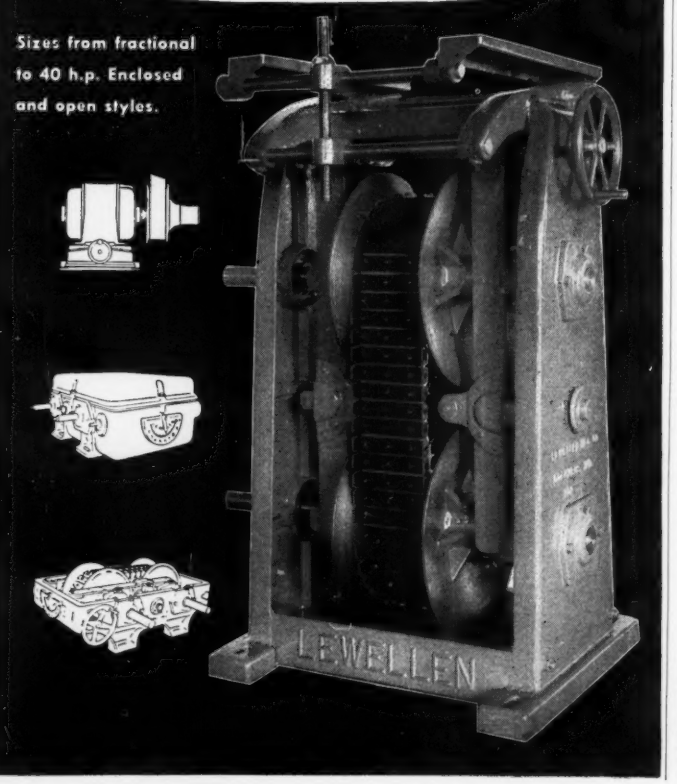
May we apply this experience and this ideal as we tackle your speed-control problem?

Actually, fixed-speed machines can do so much, and no more. A Lewellen Variable-Speed Transmission or Variable-Speed Motor Pulley makes a machine flexible and, thereby increases production and assures product uniformity—IT BECOMES AN INTEGRAL PART OF ANY PRODUCTION MACHINE. Often Lewellen Controlling Devices perform modern production miracles.

We want to help you now when such help may be of vital importance. That's why we say, "LOOK TO LEWELLEN." Wire, phone or write TODAY!

LEWELLEN MANUFACTURING CO.
COLUMBUS, INDIANA

Sizes from fractional to 40 h.p. Enclosed and open styles.



sales and service. Martin R. Howe, who represented the company in the New England territory, will succeed Mr. Streicher in Chicago. Mr. Howe will also cover St. Louis and southern Wisconsin.

♦

Election of Warren F. Fryburg as vice president of Black & Decker Electric Co. has been announced. His previous position was that of sales manager.

♦

Serving the Rocky Mountain territory, as well as Kansas City, Mo., Claude S. Slocum has been appointed representative for General Controls Co., Glendale, Calif. His new headquarters will now be located at 2135 South Adams street, Denver.

♦

As a result of increased wartime needs for its plastics, Celanese Celluloid Corp. plastics division of Celanese Corp. of America, has expanded its sales personnel. Among these is the appointment of David S. Hoppins as director of sales development.

♦

Associated with the brass and copper industry for the past seven years, Thad Smith Jr. has been made district manager at Houston, Texas, of Bridgeport Brass Co.

♦

Another plant for the manufacture of Lucite for noses, gun turrets and other sections of military airplanes has started production, according to an announcement by the Plastics department of E. I. du Pont de Nemours & Co. The buildings formerly used in fabricating unessential plastic articles were renovated and converted to form the new unit.

♦

Previously an executive of Moraine Products division, General Motors Corp., Earl S. Patch is now sales manager with Henry L. Crowley & Co. Inc., West Orange, N. J. Mr. Patch is well known in the powder metallurgy field.

♦

G. C. Brown has become Detroit engineering representative for Aircraft Screw Products Co. Inc. He had previously been sales engineer for Bohn Aluminum & Brass Corp.

♦

Naming of Carter C. Higgins, formerly general sales manager, as vice president has been announced by Worcester Pressed Steel Co., Worcester, Mass.

♦

Formerly connected with Vulcan Foundry Co., James L. Francis has joined the metallurgical staff of the Meehanite Metal Corp.

♦

Three additions to the sales staff of Wheelco Instruments Co., Chicago, have been made. Hugh Acock, formerly in the Tulsa territory, has been named Texas district manager with headquarters in Houston. C. H. Garrison is covering the Kansas City territory, including western counties of Missouri. Russell George has joined the sales department of the combustion safeguard division, and his headquarters will be in Chicago.

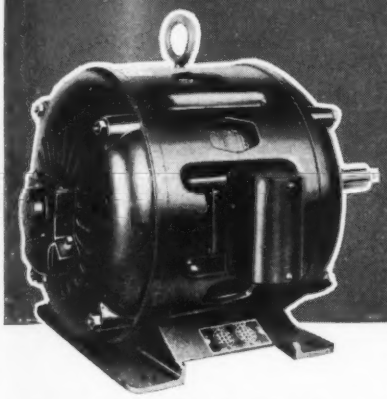
♦

Six new representatives have been added to the national sales and service staffs of McKenna Metals Co., Latrobe, Pa. They are: Frederick J. Leonard Co., 514 Eighteenth street, Denver; Bernhard Minch, P. O. Box 823, Tudor Arms Hotel, Buffalo; P. D. Browne, 1124 Allen building, Dallas; M. L. Ratcliff, 422 Smith Tower, Seattle; W. G. Todd, Engineering

IN TIME OF WAR AND IN TIME OF PEACE...

Wagner MOTORS

reflect sound engineering and modern manufacturing methods



Wagner type RP Squirrel-Cage Motors are used on machine tools and other electrically-driven equipment that operate in clean, dry locations. 1/6 to 400-hp, 25 to 60 cycle, 2-or 3-phase.

Wagner type CP Totally-Enclosed Fan-Cooled Motors are used on machine tools and other motor-driven equipment, where dust. dirt, filings, chips, fumes and other destructive elements are prevalent. 1-1/2 to 125 hp, 25 to 60 cycle, 2- or 3-phase.

Wagner type HP Explosion-Proof Motors are ideal for machines located where inflammable materials and substances are handled or manufactured. 3/4 to 125 hp, 2- or 3-phase, 25 to 60 cycle.

M43-11

THE skill and facilities Wagner has gained in 52 years of manufacturing quality motors are now being used to speed up Victory. Wherever there is war activity you will find Wagner motors doing a job—on ships, tanks, and planes...in army cantonments and navy yards . . . on motor driven machinery and equipment in shipyards, in mines and in all kinds of plants producing war materials.

Wagner motors have proved their ability to produce dependable power under the most severe operating conditions and they can help you, too, in your war effort.

No matter what type of motor you require — regardless of the torque, speed, or current requirements, you can choose a motor from the Wagner line that is correctly engineered for the job. The three motors illustrated represent just a few of the various types of Wagner motors. Each Wagner motor has special electrical and mechanical characteristics that make it the ideal motor for certain applications.

FIELD ENGINEERING SERVICE

Wagner's 29 branches are manned by trained field engineers competent to solve your motor application problems. They will gladly consult with you and do everything possible to assure you the quickest delivery on the motors you need to keep war production on schedule.

Send for These Valuable Bulletins... Bulletins MU-182 and MU-183 illustrate and describe the complete line of Wagner motors—a motor for every purpose. Copies of these bulletins will be sent upon request.

Wagner Electric Corporation

ESTABLISHED 1891

6404 Plymouth Avenue, St. Louis, Mo., U. S. A.

ELECTRICAL AND AUTOMOTIVE PRODUCTS

BEARINGS

IN ENDLESS VARIETY FOR DESIGNERS WHO PLAN

"Perfection"

WAR is the great stimulator—creates the necessity that in turn creates new standards of speed, strength, efficient performance; creates new and better products to meet these standards.

In the forefront of war production, in the forefront of post-war product pioneering is the anti-friction bearing.

In your planning for tomorrow, use Ahlberg's counsel.

Here you'll find a group of competent engineers, with a broad knowledge of industry's requirements and experienced in planning of new products.

Ahlberg also offers a full line of bearings; all types—ball, roller, thrust and mounted units—to meet every anti-friction need.

A LETTER TO US ARRANGES A CONTACT, 26 BRANCHES TO SERVE YOU

AHLBERG BEARING COMPANY

CJB AHLBERG

3017 WEST 47th STREET • CHICAGO, ILL.

Coast West as PRECISION BEARINGS, INC Los Angeles

Sales Co., 308 Carandelet building, New Orleals; and W. E. Seibold, Engineering Sales Co., 14 East Eighteenth street, Tulsa, Okla.

♦

Greene, Tweed & Co., New York, makers of mechanical packings, has announced the appointment of J. J. McIntosh as southeastern sales representative. Mr. McIntosh will be located at 1106 McLynn avenue, Atlanta. Another appointment is that of B. F. Coombs as Texas sales representative, located at Route 12, Box 495, Houston.

♦

Removal of offices of Metallizing Engineering Co. to its new location at 38-14 Thirtieth street, Long Island City, N. Y., has been made. The entire building will be devoted to production, warehouse and executive offices, as well as experimental and research laboratories for development of the company's process.

♦

With headquarters in New York, A. Elliott Maxwell has been appointed vice president of Whiting Corp., Harvey, Ill.

MEETINGS AND EXPOSITIONS

June 7-9—

American Electroplaters Society. Annual meeting to be held at Hotel Statler, Buffalo, N. Y. William J. R. Kennedy, 93 Oak Grove avenue, Springfield, Mass., is executive secretary.

June 9-10—

Society of Automotive Engineers Inc. War Materiel meeting to be held at the Book Cadillac hotel, Detroit. John A. C. Warner, 29 West Thirty-ninth street, New York, is secretary and general manager.

June 14-16—

American Society of Mechanical Engineers. Semiannual meeting to be held in Los Angeles, Calif. C. E. Davies, 29 West Thirty-ninth street, New York, is secretary.

June 21-25—

American Institute of Electrical Engineers. National technical meeting to be held in Cleveland. H. H. Henline, 33 West Thirty-ninth street, New York, is national secretary.

June 28-July 2—

American Society for Testing Materials. Annual meeting to be held at the William Penn hotel, Pittsburgh. R. E. Hess, 260 South Broad street, Philadelphia, is assistant secretary.

Set. 23-24—

Society of Automotive Engineers Inc. National tractor meeting to be held at the Schroeder hotel, Milwaukee. John A. C. Warner, 29 West Thirty-ninth street, New York, is secretary and general manager.

Sept. 28-30—

Association of Iron and Steel Engineers. Annual convention to be held at Hotel William Penn, Pittsburgh. Brent Wiley, Empire building, Pittsburgh is managing director.

Sept. 30-Oct. 2—

Society of Automotive Engineers. Aircraft engineering and production meeting at the Biltmore hotel, Los Angeles. John A. C. Warner, 29 West Thirty-ninth street, New York, is secretary and general manager.

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